TENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference Cas 0202	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/CH 01/ 00118	International filing date *(day/month/year)* 23/02/2001	(Earliest) Priority Date *(day/month/year)* 25/02/2000
Applicant CSEM CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHN		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readble form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. ☐ **Certain claims were found unsearchable** (See Box I).

3. ☐ **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

☐ the text is approved as submitted by the applicant.

☒ the text has been established by this Authority to read as follows:

SWITCHING DEVICE,PARTICULARLY FOR OPTICAL SWITCHING

5. With regard to the **abstract,**

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

☒ as suggested by the applicant.

☐ None of the figures.

☐ because the applicant failed to suggest a figure.

☐ because this figure better characterizes the invention.

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

GRESSET-LAESSER-NITHARDT
Cabinet de Conseils en Propriété Industrielle
Puits-Godet 8A
CH-2000 Neuchâtel
SUISSE

Date of mailing (day/month/year) 26 October 2001 (26.10.01)	
Applicant's or agent's file reference Cas 0202	**IMPORTANT NOTIFICATION**
International application No. PCT/CH01/00118	**International filing date** (day/month/year) 23 February 2001 (23.02.01)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
CSEM CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA Jaquet Droz 1 CH-2007 Neuchâtel Switzerland	CH	CH
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[X] the person [ ] the name [ ] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
COLIBRYS SA Maladière 83 CH-2007 Neuchâtel Switzerland	CH	CH
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[ ] the International Preliminary Examining Authority
[X] the designated Offices concerned
[ ] the elected Offices concerned
[ ] other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Beate GIFFO-SCHMITT Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

To:
GRESSET-LAESSER-NITHARDT
Cabinet de Conseils en Propriété Industrielle
Puits-Godet 8A
CH-2000 Neuchâtel
SUISSE

15 SEP. 2001

Date of mailing (day/month/year) 30 August 2001 (30.08.01)		
Applicant's or agent's file reference Cas 0202	**IMPORTANT NOTICE**	
International application No. PCT/CH01/00118	**International filing date** (day/month/year) 23 February 2001 (23.02.01)	**Priority date** (day/month/year) 25 February 2000 (25.02.00)
Applicant CSEM CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA et al		

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:
   US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:
   EP

   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on 30 August 2001 (30.08.01) under No. WO 01/63337

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, **a demand for international preliminary examination** must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the **national phase**, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Gen va 20, Switzerland**	Authorized officer J. Zahra
Facsimile No. (41-22) 740.14.35	Telephone No. (41-22) 338.83.38

INTERNATIONAL SEARCH REPORT

Int[illegible] Application No
PCT/[illegible]01/00118

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B26/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, EPO-Internal, PAJ, INSPEC, IBM-TDB, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 794 761 A (FALCO LUCIEN ET AL) 18 August 1998 (1998-08-18) column 4, line 39 -column 6, line 64; figures 1-5 & FR 2 726 135 A (CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA) 26 April 1996 (1996-04-26) cited in the application ---	1,2,9-11
X	US 5 612 815 A (LABEYE PIERRE ET AL) 18 March 1997 (1997-03-18) column 1, line 40 -column 2, line 54 column 6, line 50 -column 7, line 2; figures 1,5A,5C --- -/--	1,9

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 May 2001	21/05/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hylla, W

INTERNATIONAL SEARCH REPORT

Inte[illegible]ional Application No
PCT[illegible]01/00118

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 286 337 A (BRITISH TELECOMM) 12 October 1988 (1988-10-12) abstract; figures 2,7 page 3, line 17 - line 24 page 5, line 22 - line 40 ---	1,9
A	EP 0 510 629 A (TEXAS INSTRUMENTS INC) 28 October 1992 (1992-10-28) abstract; figures 5,6,7B -----	1

INTERNATIONAL SEARCH REPORT

Informatio[illegible]tent family members

Int[illegible]ional Application No
PCT/[illegible]1/00118

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5794761	A	18-08-1998	FR	2726135	A	26-04-1996
			EP	0709706	A	01-05-1996
US 5612815	A	18-03-1997	FR	2729232	A	12-07-1996
			EP	0722103	A	17-07-1996
			JP	8248335	A	27-09-1996
EP 0286337	A	12-10-1988	AT	86394	T	15-03-1993
			AU	602078	B	27-09-1990
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			DE	3878710	A	08-04-1993
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			DE	69221196	T	08-01-1998
			JP	6148540	A	27-05-1994
			KR	261400	B	01-07-2000

PCT/CH 01 / 00118

Eur päisches Patentamt	European Patent Office	Office européen des brevets

REC'D 06 MAR 2001
WIPO PCT

CH 01/118

Bescheinigung Certificate Attestation

E. U

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.	The attached documents are exact copies of the European patent application described on the following page, as originally filed.	Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. Patent application No. Demande de brevet n°

00810162.8

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN
COMPLIANCE WITH
RULE 17.1(a) OR (b)

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

Hatten

I.L.C. HATTEN-HECKMAN

DEN HAAG, DEN
THE HAGUE, 06/02/01
LA HAYE, LE

Europäisches Patentamt | Eur pean Patent Office | Office europ´en des brevets

Blatt 2 d r Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

Anmeldung Nr.:
Application no.: 00810162.8
Demande n°:

Anmeldetag:
Date of filing: 25/02/00
Date de dépôt:

Anmelder:
Applicant(s):
Demandeur(s):
C.S.E.M. CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA
2007 Neuchâtel
SWITZERLAND

Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention:
Switching device, particularly for optical switching

In Anspruch genommene Prioriät(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

Staat: State: Pays:	Tag: Date: Date:	Aktenzeichen: File no. Numéro de dépôt:

Internationale Patentklassifikation:
International Patent classification:
Classification internationale des brevets:
G02B26/02

Am Anmeldetag benannte Vertragstaaten:
Contracting states designated at date of filing: AT/BE/CH/CY/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE/
Etats contractants désignés lors du depôt:

Bemerkungen:
Remarks:
Remarques:
See for original title page 1 of the description.

SWITCHING DEVICE

This invention is a switching device comprising a cell which includes a structure capable of moving back and forth between two end positions and actuating electrodes to subject the structure to attraction forces to control its movement.

Devices of this type are used, in particular, to influence or interrupt the trajectory of optical beams in systems which control, process and store information on pixel-based images. One particularly interesting application for these systems is for printing or high definition reproduction systems.

French patent FR 2 726 135 describes one such device, made in the form of a micro-mechanical structure, and an installation for optical switching using several devices placed in an array.

This invention aims to improve the reliability, durability and performance of the above-mentioned device. In particular, the aim of the invention is to provide a switching device where the cell is equipped with a moving structure which moves in a regular way in a single plane, does not rebound when it reaches its end positions and where there is little risk of remaining stuck to the electrodes.

In order to achieve these goals, the switching device according to the invention is characterised by the actuating electrodes of its cell being positioned on both sides of the moving structure, in such a way as to follow the exact shape of said moving structure when it is at either of its two end positions.

This device also benefits from one or several of the main characteristics listed below.

- The moving structure is formed by a flexible cantilever beam and a screening blade integrally connected to the beam. In this case, the electrodes are only located on each side of the beam.
- Adjacent to each electrode there is at least one stopper serving as a stop for the beam and intended to prevent it from coming into contact with the electrode. This stopper is, for instance, located at the free end of the cantilever beam, beyond the screen. Furthermore, it is preferable

to provide for several stoppers distributed along the whole length of the electrodes.

- The side walls of the moving structure, stoppers and electrodes are coated with a layer of diamond, preferably made to act as a conductor, or any material with the same properties.
- The switching device is made on a substrate which has a transverse aperture positioned in such a way as to be closed by the screen when the system is in one of its end positions. This aperture has, on the substrate's side opposite the screen, one portion with a greater diameter than its portion located on the side of the screen. It is preferable if this portion is conical.
- The beam has either a 'T' shaped cross-section or any other shaped cross-section able to enhance its out-of-plane rigidity.
- Each electrode connected to a conductor is connected to a control circuit; the connection of the electrode to this conductor may comprise an incorporated fuse.

Other characteristics and advantages of the invention will be shown in the description below, made with regard to the attached drawings in which:

- Figure 1 is a top-view of a switching cell according to the invention;
- Figure 2 is a cross-section according to II-II of the cell in Figure 1;
- Figure 3 is a cross-section according to III-III of the cell in Figure 1, and
- Figure 4 is a schematic representation of a four cell array with their interconnections.

Figures 1 to 3 show a substrate (10), preferably made from silicon, on which is attached, by means of an anchoring area (12), an elastic cantilever beam (14) with, in this particular embodiment, a 'T' shaped cross-section with, on its free

end, a rectangular screen (16). It is preferable that the beam (14) and screen (16) are made of polysilicon made to act as a conductor by doping.

The beam (14) and screen (16) make up a moving structure, the screen being able to be moved alternately between the two end positions, A and B respectively, represented by solid and dotted lines. These positions are defined by two end stoppers (18), located on the substrate (10), which act to stop the beam (14).

The screen is brought to these end positions under the effect of electrostatic forces generated by a pair of addressing electrodes (20), made of doped polysilicon and attached to the substrate by an isolating layer (22), on both sides of the beam (14) and along its length, in such a way as to follow its exact shape as closely as possible without, however, touching it, when the screen occupies positions A and B respectively.

Preferably, the isolating layer (22) is formed by a coating of silicon dioxide (SiO2) deposited on the substrate and a layer of silicon nitride (Si3N4) deposited on the dioxide coating.

The electrodes (20) have, along their length, zones within which are located pairs of stoppers (24), which may, for instance, be identical to the end stoppers (18), one of the five in the example given, electrically isolated from the electrodes and intended to limit movements of the beam so that it does not come into contact with the electrodes.

It is preferable if the side walls of the beam (14), stoppers (18, 24) and electrodes (20) are coated with a diamond layer made to be hydrophobic and conducting by means of an appropriate doping treatment, known by those skilled in the art. As well as diamond, any other material which has the same properties or such other properties as to avoid in-use stiction, particularly a polymer, self-assembled mono-layers, teflon or alike may also be used for this coating.

At the centre of the portion closed by the screen (16) when it is in position A, the substrate (10) has a transverse aperture (26) which, on the screen side, has a preferably cylindrical portion (26a) of a slightly smaller diameter to that of the screen side, and a gradually widening portion (26b) which is preferably

conical. It should be noted that instead of being rectangular, the screen might be of any shape and size which makes it capable to cover the aperture when the beam is in its closed position.

According to an advantageous embodiment of the invention, the substrate (10) is made of a transparent material, such as quartz.

In its central portion, above which the beam (14) and the screen 16 move, the substrate is coated with a doped polysilicon layer (28) electrically connected to the beam, stoppers and screen in such a way as to have the same potential and to thus prevent any attraction between them.

The cell described is preferably not used individually, but in association with other identical cells arranged in lines and columns and forming a regular array which, as already known in the art, may be, among other arrangements, rectangular, honeycombed or hexagonal.

Figure 4 shows, schematically, four identical cells C1, C2, C3 and C4, located in an array made up of two rows and two columns. The beam (14), the screen (16) and the pair of electrodes (20) can be found.

The anchoring areas (12) of cells C1 and C2 on the upper row are connected to a common line conductor (30). In the same way, the anchoring areas (12) of cells C3 and C4 on the lower row are connected to another common line conductor (32).

The right-hand electrodes (20) of the right-hand cells C2 and C4 are connected to a common right-hand column conductor (34), while the left-hand electrodes (20) of these cells are connected to a common left-hand column conductor (38). In the same way, the right-hand electrodes (20) of the left-hand cells C1 and C3 are connected to another common column conductor (36), while the left-hand electrodes (20) of these cells are connected to another common column conductor (40).

For details on how to control cells in this type of array, reference is made to the above-mentioned patent FR 2 726 135.

It is known that, despite the precautions taken, and in particular, the presence of stoppers (18, 24), there may be a risk of short-circuit, caused, in particular,

by the beam (14) coming into contact with an electrode (20). In order to prevent such an accident from causing the failure of all the cells in the same line and or column, which can occur in known systems, it is proposed that the connection of each of the electrodes (20) with its column conductor to be made, as shown in Figure 4, by the intermediary of a fuse (42) which, for instance, could be made in the form of a narrow section of the connection line.

A switching cell is thus produced for which the main advantages when compared to known embodiments, particularly as described in patent FR 2 726 135, are listed below:

- Due to the fact that, on the one hand, the electrodes are positioned in such a way as to exactly match the beam when it is in either of its two end positions and that, on the other hand, the screen itself is not subjected to the direct action of the electrodes, the movement of the moving structure becomes regular, in a single plane, and is free from - or at least has limited - rebounds;

The presence of stoppers distributed along the length of the electrodes contributes equally to this operation in a smooth way while at the same time reducing the risk of the beam sticking to the stoppers;

- The structured section of the beam prevents out-of-plane bending and therefore also contributes to the system always moving parallel to the substrate;

The presence of a conductive diamond coating on the side walls as regards the beam, electrodes and stoppers prevents the accumulation of charges that cause the beam to stick to the stoppers;

The fuse located between each electrode and the conductor of the associated column and/or line will limit the consequences of a short-circuit occurring in a cell;

- Finally, the conical section of the aperture in the substrate prevents loss of light and significantly improves the optical transmission of the device.

Claims

1. Switching device comprising at least one cell made up of a moving structure capable of moving between two end positions and actuating electrodes for subjecting this structure to forces of attraction to control its movement, characterised in that said electrodes are located on each side of the moving structure in such a way as to follow its exact shape when it is in one of its two end positions.
2. Switching device according to Claim 1, characterised in that said moving structure comprises a flexible cantilever beam and an integral screen attached to said beam.
3. Switching device according to Claim 2, characterised in that said electrodes are located only on each side of the flexible beam.
4. Switching device according to Claims 2 or 3, characterised in that it also comprises, associated with each electrode, at least one stopper serving as a stop for the beam and for the purpose of preventing it coming into contact with said beam.
5. Switching device according to Claim 4, characterised in said stopper is located at the free end of the cantilever beam, beyond the screen.
6. Switching device according to Claims 4 or 5, characterised in that it comprises a plurality of stoppers distributed along the length of said electrodes.
7. Switching device according to one of the claims 1 to 6, characterised in that the side walls of the moving structure, stoppers and electrodes are coated with a diamond layer.
8. Switching device according claim 7, characterised in that said diamond layer is conductive.
9. Switching device according to one of the claims 1 to 8, characterised in that it is made on a substrate.

10. Switching device according to claim 9, characterised in that said substrate is made of transparent material.

11. Switching device according to Claim 9, characterised in that the substrate has a transverse aperture positioned in such a way as to be closed by the screen when the system is in one of its end positions.

12. Switching device according to Claim 11, characterised in that said aperture, on the opposite side to the screen, has a portion of a greater diameter than the portion located on the side of the screen.

13. Switching device according to Claim 12, characterised in that said portion of greater diameter is conical.

14. Switching device according to Claims 2 to 13, characterised in that said beam presents a 'T' shaped section.

15. Switching device according to Claims 1 to 14, in which each electrode is connected to a conductor linked to a control circuit, characterised in that the electrode connection with the above-mentioned conductor comprises a fuse.

Title : Switching device

ABSTRACT

This switching device comprises at least one cell made up of a moving structure consisting in a flexible cantilever beam (14) and an integral screen (16) attached to said beam, being able to move between two end positions (A, B) and of actuating electrodes for subjecting said structure to forces of attraction to control its movements.

Electrodes (20), stopping means (18, 24) and beam structure are provided to ensure a regular movement of the moving structure and a reliable operating of the switching device.

This invention may be used in optical switching applications.

(Figure 1)

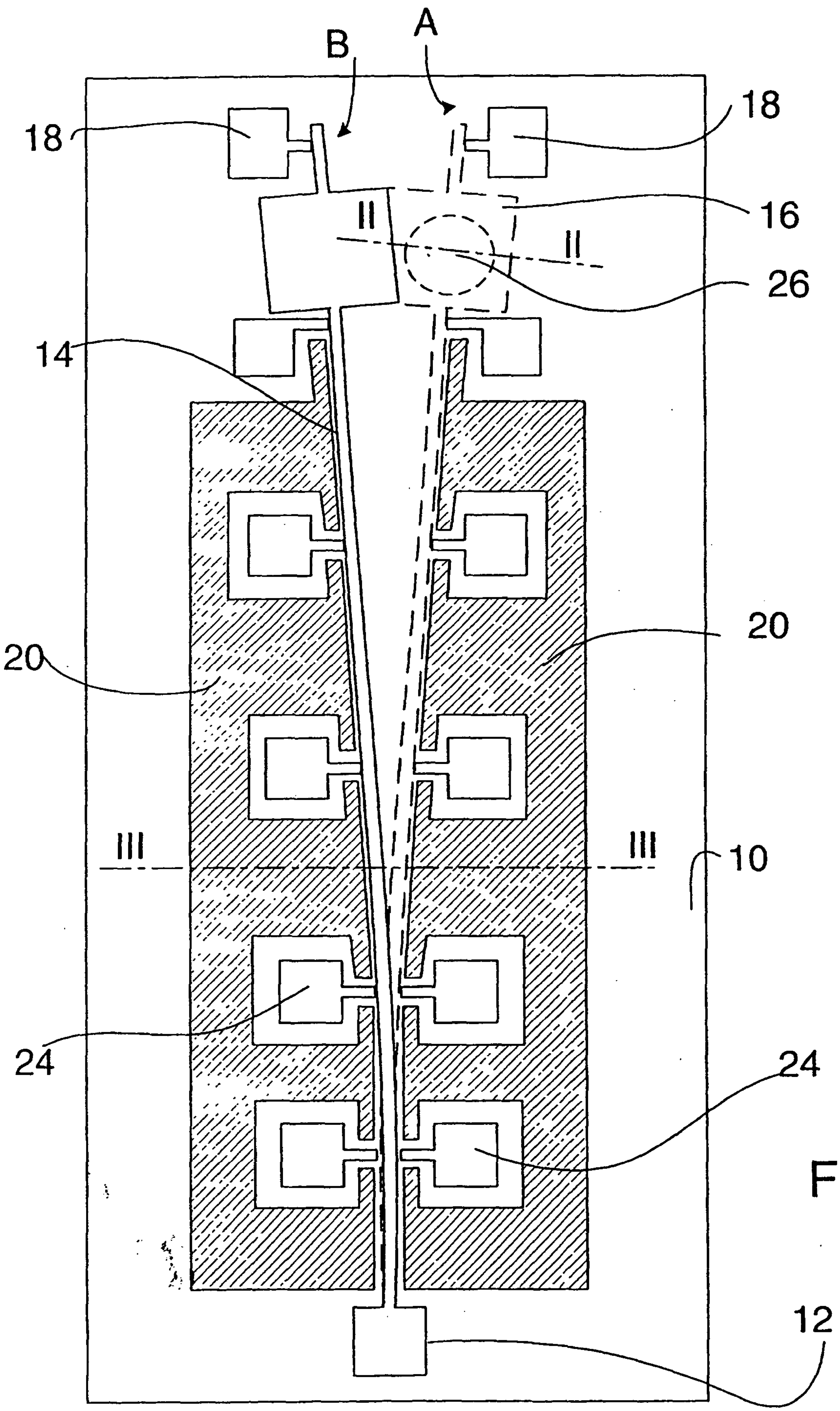

Fig. 1

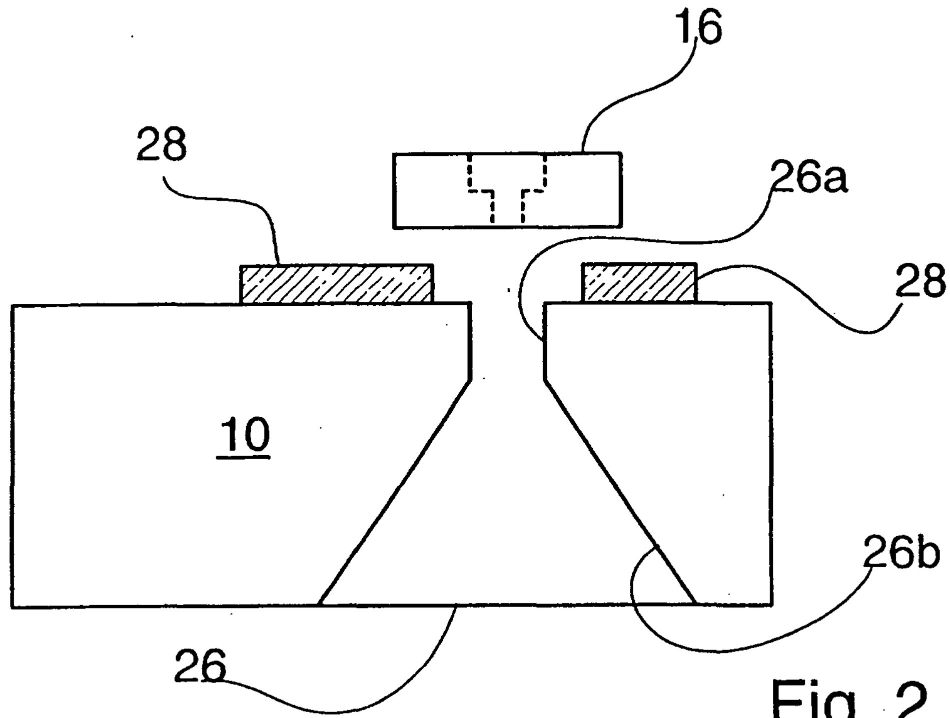

Fig. 2

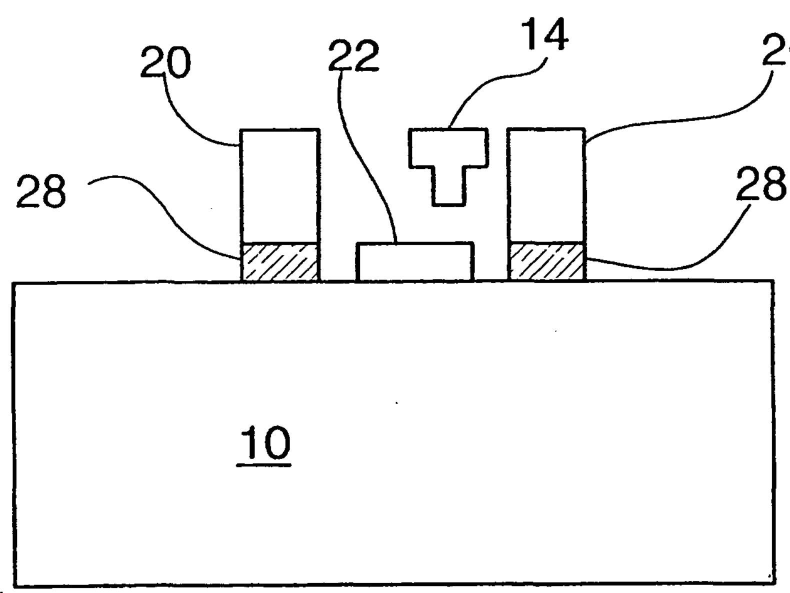

Fig. 3

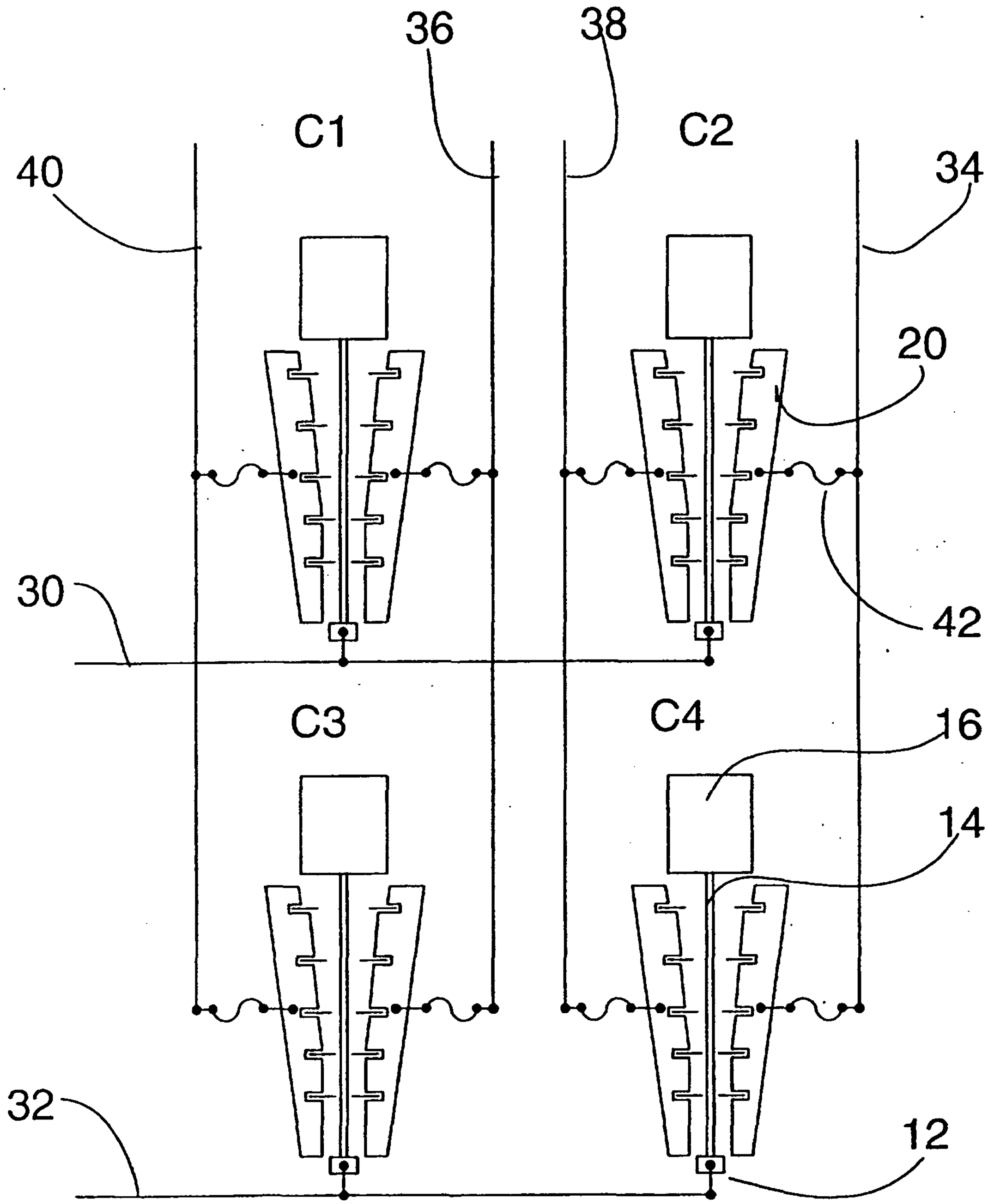

Fig. 4

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 286 337 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 88302979.5

(22) Date of filing: 31.03.88

(51) Int. Cl.4: G02B 26/02

(30) Priority: 02.04.87 GB 8707854

(43) Date of publication of application: 12.10.88 Bulletin 88/41

(84) Designated Contracting States: AT BE CH DE ES FR GB GR IT LI LU NL SE

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(74) Representative: Greenwood, John David et al
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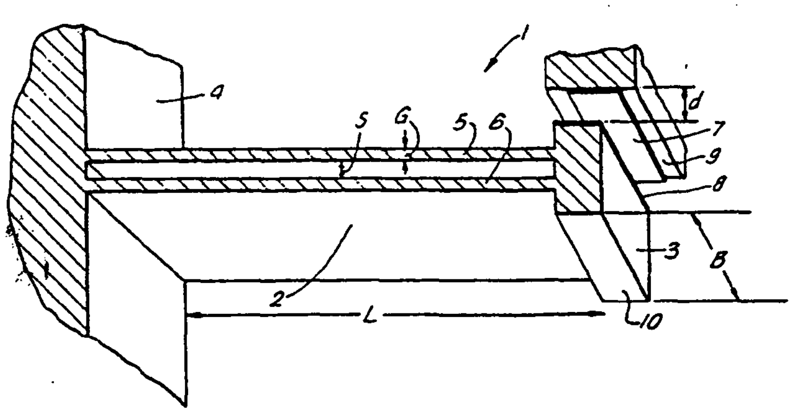
(54) **Radiation deflector assembly.**

(57) A micromechanical cantilever beam (1) for use in an optical switch or other radiation deflector assembly includes a beam portion (2) comprising two parallel arms (5,6) hinged at one end to a supporting substrate (4) and at the other end to a load portion (3) which provides the major proportion of the total mass of the cantilever beam. The beam is deflected by the application of an electrostatic potential between electrodes on opposing surfaces (8,9) of the load portion and the supporting substrate respectively. This structure has improv d switching performance in operation.

Fig.1.



EP 0 286 337 A1

RADIATION DEFLECTOR ASSEMBLY

The present invention relates to radiation deflectors and radiation deflector assemblies and in particular to radiation deflectors and assemblies of the kind described in co-pending patent application PCT GB 86/00630 filed 16 October 1986 in the name of the present applicants.

Radiation deflector assemblies described in PCT GB 86/00630 comprise at least three radiation waveguides; a controllable radiation deflector positioned such that when the deflector is in a first position radiation passes between one combination of two of the waveguides, and when the deflector is in a second position radiation passes between another combination of two of the waveguides; and control means responsive to control signals for controlling the position of the deflector. In the specific embodiment described in PCT GB 86/00630 the deflector comprises a cantilever beam mounted and hinged in a common substrate with the waveguides. This configuration of radiation deflector assembly hereinafter referred to as "of the kind described" eases the problem of accurately aligning the waveguides with the deflector.

Radiation deflector assemblies of the kind described find application as radiation switches, for example, as optical switches in optical transmission systems.

One problem with the contruction of radiation deflector assemblies of the kind described is the need to make the radiation deflector attain equilibrium as rapidly as possible on switching, without excessive resonant oscillation. The deflector must also have a minimum displacement sufficient to deflect radiation by a distance at least equal to the separation between each of the waveguides in respective waveguide pairs.

It is further desirable that where the control means requires a driving potential to control deflection of the deflector, this driving potential is minimised.

It is an object of the present invention to provide improved radiation deflectors and deflector assemblies of the kind described which resolve or at least partially mitigate one or more of these aforementioned problems.

According to the present invention a radiation deflector comprises a deflectable cantilever beam of which one end is free and one end is hinged to a supporting substrate wherein the cantilever beam has its centre of mass closer to the free end of the beam than to the hinged end.

Also according to the present invention a radiation deflector assembly of the kind described comprising a deflectable cantilever beam of which one end is free and one end is hinged to a supporting substrate is characterised in that the cantilever beam has its centre of mass closer to the free end of the beam than to the hinged end.

Conveniently, the cantilever beam comprises a beam portion hinged to the substrate and a load portion at the free end of the beam portion. Preferably the load portion provides the major proportion of the total mass of the cantilever beam as a whole, the centre of mass of the load portion being arranged to be positioned at or near the free end of the beam portion.

It has been found that a cantilever beam radiation deflector according to the present invention facilitates the more rapid attainment of equilibrium on switching.

Preferably the length of the beam portion and the mass of the load portion are selected such that the first natural resonant frequency of the cantilever beam is much greater than the maximum frequency at which the deflector is to be switched between positions.

Conveniently, in a radiation deflector assembly according to the invention, the control means comprises means for applying an electrostatic potential for displacing the cantilever beam deflector. The control means may include an electrode arranged such that the displacement force provided by an applied electrostatic potential effectively acts at the centre of mass of the load portion.

Conveniently, the electrostatic potential may be applied to a side surface, being a surface of the load portion substantially parallel to the longitudinal axis of the undisplaced beam portion. Preferably the area of the side surface is made relatively great in order to reduce the electrostatic potential required to provide the necessary displacement force.

Embodiments of the invention will now be described in detail and by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic illustration of a cantilever beam radiation deflector according to the present invention;

Figure 2 is a cutaway perspective view of a substrate with a cantilever beam radiation deflector according to the present invention;

Figure 3 is a diagram illustrating one mode of operation of a radiation deflector according to the invention;

Figure 4 illustrates an alternative mode of operation;

Figure 5 is a graph illustrating the ranges of beam geometries appropriate for desirable performance criteria;

Figure 6 is a graph of cantilever stiffness versus arm spacing and thickness for a cantilever with a beam portion comprising two parallel arms; and

Figure 7 is a diagram illustrating the stages in an exemplary method of fabrication of a cantilever beam radiation deflector according to the invention in a silicon substrate.

In Figure 1 a cantilever beam radiation deflector 1 comprises a beam portion 2 which extends out from the body of supporting substrate 4 and carries a load portion, or end mass 3, at the end not attached to the substrate. In this embodiment the beam portion 2 is formed of two parallel arms 5, 6. An area 9 of the supporting substrate 4 adjacent to the end mass 3 is provided with an electrode 7 disposed parallel to and opposite a lateral surface 8 of the end mass 3. The surface 8 is shown also provided with an electrode.

In operation, the cantilever may be deflected by applying an electrostatic potential between the electrodes. The parallel arms 5, 6 are adapted to flex at the joints to the body of the substrate 4 and at thejoints to the end mass 3. This arrangement permits the electrode surfaces to remain parallel even when the beam portion is deflected.

Figure 2 is a cutaway perspective view of an alternative cantilever beam radiation deflector 20. The cantilever beam deflector 20 again comprises a beam portion 22 formed of two parallel arms 25, 26, extending out from a supporting substrate 24, together with a massive load portion, or end mass 23. The load portion 23 in this instance is H-shaped and is arranged to have its centre of mass in the plane of the attachment of the load portion to the two parallel arms 25, 26.

In this configuration the sides 28, 30 of the load portion 23 are readily available for use with electrostatic electrodes. The proportionately large area of these sides reduces the magnitude of the electrostatic driving potential needed to displace the deflector.

One mode of operation of a radiation deflector assembly of the kind described is illustrated in plan - schematic in Figure 3. As in Figure 2, the deflector shown comprises an H-shaped load portion 33 attached to a supporting substrate 34 by two parallel arms 35, 36. Three waveguides 300, 301, 302 are provided in the substrate 34 and are arranged such that radiation passed along the waveguides is deflected off one side surface 38 of the load portion 33. The side surface 38 is provided with a coating exhibiting suitably high reflectivity at the operating wavelength of.

In Figure 3(a) the radiation deflector is undisplaced from its equilibrium position and radiation is directed between the two waveguides 300 and 301 as shown by the dotted line. In Figure 3(b) the radiation deflector is displaced towards the waveguides by means of electrostatic attraction between electrodes on the opposing faces 38, 39 of the load portion 33 and the supporting substrate 34 respectively. In this position radiation is directed between waveguides 300 and 302, again as shown by the dotted line.

An alternative embodiment and mode of operation is illustrated in Figure 4. In this embodiment a waveguide 400 is mounted longitudinally along the beam portion of the deflector and parallel with the arms 45, 46. This waveguide 400 terminates at the end face 41 of the load portion 43. Three further waveguides 401, 402, 403 are mounted in the substrate 44 and terminate at the face 42 of the substrate opposing the end face 41 of the load portion 43. Electrostatic potential is applied between electrodes on opposing side faces 48, 49 of the load portion 43 and substrate 44 respectively to displace the deflector.

In the undisplaced equilibrium position of Figure 4(a) radiation is coupled between the waveguide 400 on the cantilever deflector and the central waveguide 401 on the supporting substrate. In Figure 4(b), the cantilever is displaced to couple radiation between the waveguide 400 on the cantilever deflector and the waveguide 402 on the main body of the substrate. If the cantilever were displaced in the opposite sense clearly radiation would be coupled between the cantilever waveguide 400 and the third other waveguide 403.

For optical radiation the waveguide 400 mounted on the cantilever may be an optical fibre stripped of the usual cladding and comprising the central core alone. Such a waveguide would be flexible enough to move with the cantilever beam portion and dimensionally of the appropriate scale. Over the small distances involved the excess loss introduced by an unclad fibre such as this would be negligible.

It will be apparent that radiation could be deflected into additional waveguides by suitably adjusting the degree and direction of displacement of the cantilever in both the example embodiments described here and in other embodiments within the scope of the invention.

In order to appreciate the advantages of the embodiments of the invention it is useful to analyse the mechanical characteristics of a cantilever beam, using the notation as shown in Figure 1.

Assuming that the only force acting on the cantilever is a concentrated forc , P, at the free end, then the maximum displacement y_o may be expressed as:

$$y_0 = \frac{-PL^3}{3EI} \qquad (1)$$

where L is the length of the beam and EI is the elastic stiffness of the beam. E is the elastic modulus and I is the second moment of area which may be expressed as:

$$I = \frac{BG(S+2G)}{6} \qquad (2)$$

where B is the depth of the beam, G is the arm thickness and S is the arm separation.

Where the force P is applied by an electrostatic potential V acting over an area A, the magnitude of the force is given by:

$$P = V^2 A\epsilon_0/d^2 \qquad (3)$$

where ϵ_0 is the permittivity of free space and d is the separation of the cantilever from the substrate electrode.

The first resonant frequency f of this device is given by:

$$f = 2\pi\omega = \frac{1}{2\pi}[3EI/L^3(M+0.23m)]^{0.5} \qquad (4)$$

where m and M are the masses of the cantilever beam portion and end mass respectively and ω is the natural frequency of the cantilever.

For switching applications, it is important to damp the transient vibrations as soon as possible after switching. The critical damping, C for such a device is given by:

$$C = 2m\omega \qquad (5)$$

and the rate at which the amplitude diminishes is exponential and is given by:

$$y = y_0 \exp[-\omega t] \qquad (6)$$

From the theoretical treatment above it is possible to observe how the geometrical parameters of the cantilever beam influence the mechanical response, in terms of amplitude of deflection and natural resonance, of the deflector.

For a given set of dimensional constraints, the maximum switching displacement will be determined by the electrode separation, d. As d increases then according to Equation (3) the potential V required to displace the deflector must likewise increase. This increase can be offset by making the area A over which the potential is applied as large as possible within the practical limitations, as shown in the embodiment of Figure 2, for example.

From Equations (4) and (5) it is apparent that the mass of the load portion has two significant effects. A larger mass inreases the rate at which the cantilever attains equilibrium, but at the same time it decreases the first resonant frequency. The decrease in resonant frequency which goes with a larger mass can be compensated to some extent by increasing the moment of area I, or by decreasing the length, L of the beam portion. However, changes in these parameters both involve increasing the resonant frequency at the expense of the maximum displacement, y_0. Consequently, in the limit, it is preferable to increase I or decrease L such that $y_0 = d$ for a given applied electrostatic potential.

For the purposes of demonstration, some characteristics of a cantilever deflector as shown in Figure 2 have been modelled for certain selected performance criteria. The selected criteria were that:

(i) the resonant frequency should be greater than 5KHz;

(ii) the maximum electrostatic potential for deflection should be below 100V; and

(iii) the minimum electrode spacing should be 10μm.

These figures were chosen as examples only and as such are representative rather than uniquely ideal. Similarly, the ranges of geometric parameters used in the calculations were likewise chosen as representa-

tive and should not be taken to imply any specific limitations. The choice of criteria and geometric parameters in a particular practical case must be made according to the conditions relevant to that individual case. The examples here are for general guidance alone.

In Figure 5 the solid curves show the variation in beam stiffness with b am length for end masses. M of 10-50μg. These curves represent the limiting range of beam geometries (ie length and cross-section) which have a resonant frequency of 5KHz for the given end mass. The dashed curves represent beam geometries which are able to deflect to the full electrode spacing (d = 10, 15, 18μm) with a maximum applied potential of 100V. In between a pair of these curves (one solid, one dashed) exist windows inside which the three performance criteria are met.

In Figure 6 the stiffness of the cantilever, EI, is plotted as a function of the arm spacing, S for various arm thicknesses, G.

It can be seen that the twin arm beam structure enables beam stiffness appropriate to a specific situation to be easily selected from a wide range by varying the arm thickness. The twin arm structure of the beam portion thus provides design flexibility in addition to permitting the faces of the load portion to remain oriented in the same direction whether the beam portion is deflected or not, as described earlier. Furthermore, this structure is also convenient for fabrication.

One method of fabrication of a deflector according to the invention using a (110) silicon substrate is shown diagrammatically in Figure 7. Using the notation of the Miller indices, (110) silicon has two of the four {111} planes perpendicular to the surface, aligned along the <112> surface directions. These two 'vertical' {111} planes of interest intersect each other at an angle of 70.53°. The remaining two {111} planes form an angle of 35.26° to the surface, but are not employed in this construction.

The exemplary method of device fabricaton illustrated in Figure 7 involves four masking levels and two anisotropic etching stages, both through the whole silicon wafer thickness. The fabrication of the vertical beams involves a combination of micromachining and silicon planar technology to define the deflector geometry and to align the beams accurately along <112> directions. The structures are etched using electrochemically controlled ethylene diamine as an anisotropic etchant. The main steps are:

(a) Thermal oxidation followed by photolithographic definition of the beam length and exposure of a window in the silicon equivalent to the spacing between the twin arms.

(b) Etching of a slot through the exposed silicon and subsequent photlithographic definition of the end mass and areas of the supporting substrate which will eventually form the adjacent electrode surfaces.

(c) Diffusion into the exposed {111} planes of the slot to define the arm thicknesses. This provides an accurate and reproducible method of controlling the thickness of the cantilever arms. The concentration dependence of the next anisotropic etch is used as a fine tune of the arm thickness. Further diffusion is made into the areas lithographically defined in the previous step.

(d) Masking to define the free beam and etching the exposed silicon to provide the end mass and appropriate electrode spacing.

(e) A final metallisation stage employing a shadow mask in (100) silicon and sputtering of aluminium through this mask to define the contact regions and create the electrodes between the end mass and the bulk of the substrate. Sputtering from both sides of the silicon wafer and annealing provides a uniform metallisation across the wafer thickness.

Claims

1. A radiation deflector comprising a deflectable cantilever beam of which one end is free and one end is hinged to a supporting substrate wherein the cantilever beam has its centre of mass closer to the free end of the beam than to the hinged end.

2. A radiation deflector according to claim 1 wherein the cantilever beam comprises a beam portion hinged to the substrate and a load portion at the free end of the beam portion and the load portion provides the major proportion of the total mass of the cantilever beam.

3. A radiation deflector assembly comprising at l ast three radiation waveguides; a controllable radiation deflector positioned such that when the deflector is in a first position radiation passes between one combination of two of the waveguides, and when the deflector is in a second position radiation passes between another combination of two of the waveguides; and control means responsive to control signals for controlling the position of the deflector wherein the deflector comprises a cantilever beam mount d and hinged in a common substrate with the waveguides and characterised in that the cantilever beam has its centre of mass closer to the free end of the beam than to the end hinged to the common substrate.

4. A radiation deflector assembly according to claim 3 wherein the cantilever beam comprises a beam portion hinged to the substrate and a load portion at the free end of the beam portion and the load portion provides the major proportion of the total mass of the cantilever beam.

5. A radiation deflector assembly according to claim 4 wherein the length of the beam portion and the mass of the load portion are selected such that the first natural resonant frequency of the cantilever beam is substantially greater than the maximum frequency at which the deflector is to be switched between positions.

6. A radiation deflector assembly according to claim 3 or claim 4 wherein the control means comprises means for applying an electrostatic potential for displacing the cantilever beam deflector.

7. A radiation deflector assembly according to claim 6 wherein the control means include an electrode arranged such that the displacement force provided by an applied electrostatic potential effectively acts at the centre of mass of the load portion.

8. A radiation deflector assembly according to claim 3 wherein at least one of the waveguides is provided on the cantilever beam.

9. A radiation deflector assembly according to claim 8 wherein the at least one waveguide runs longitudinally along the cantilever beam.

10. A radiation deflector substantially as hereinbefore described and with reference to the Figures.

11. A radiation deflector assembly substantially as hereinbefore described and with reference to the Figures.

Fig.1.

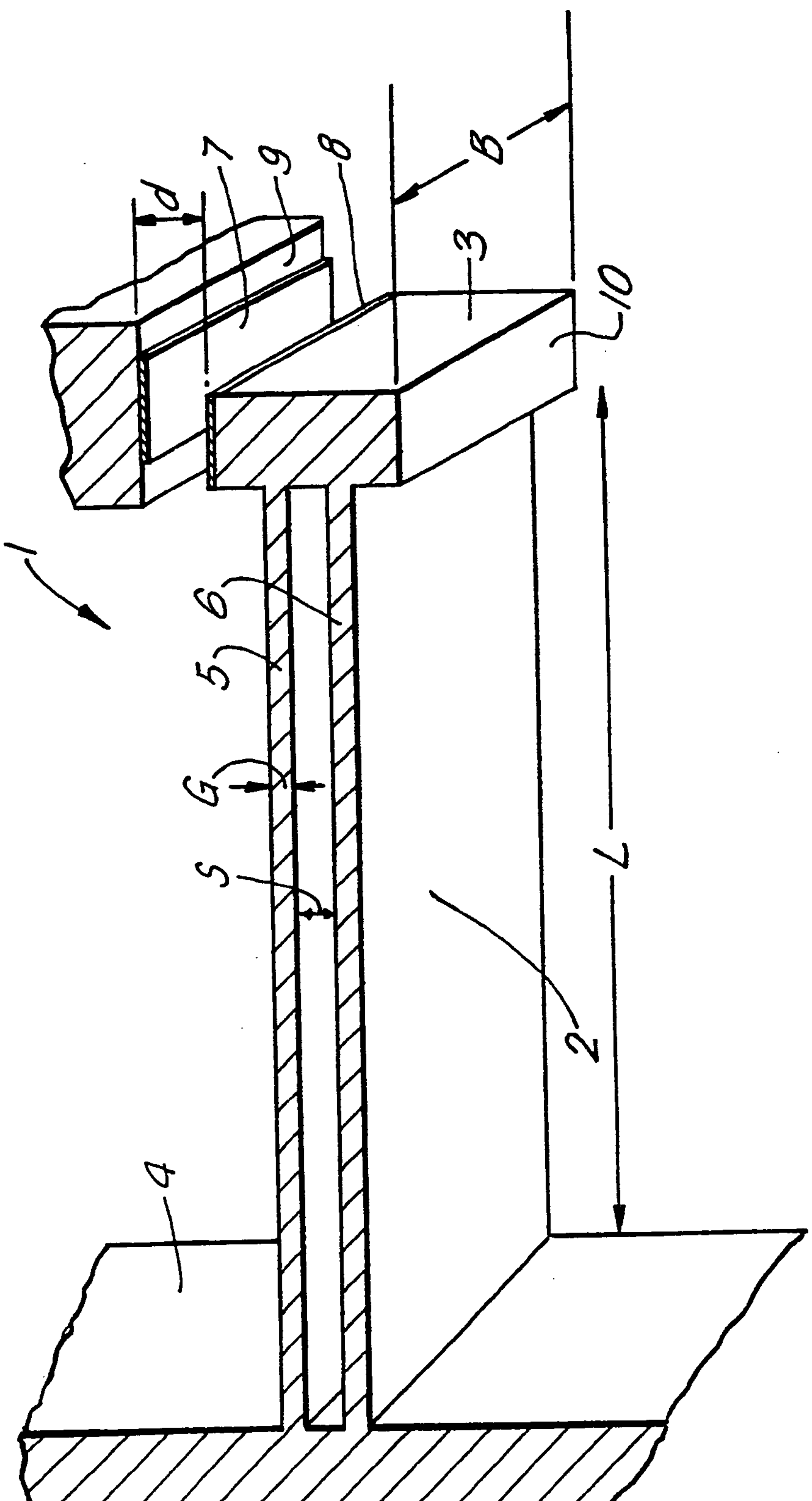


Fig. 2.

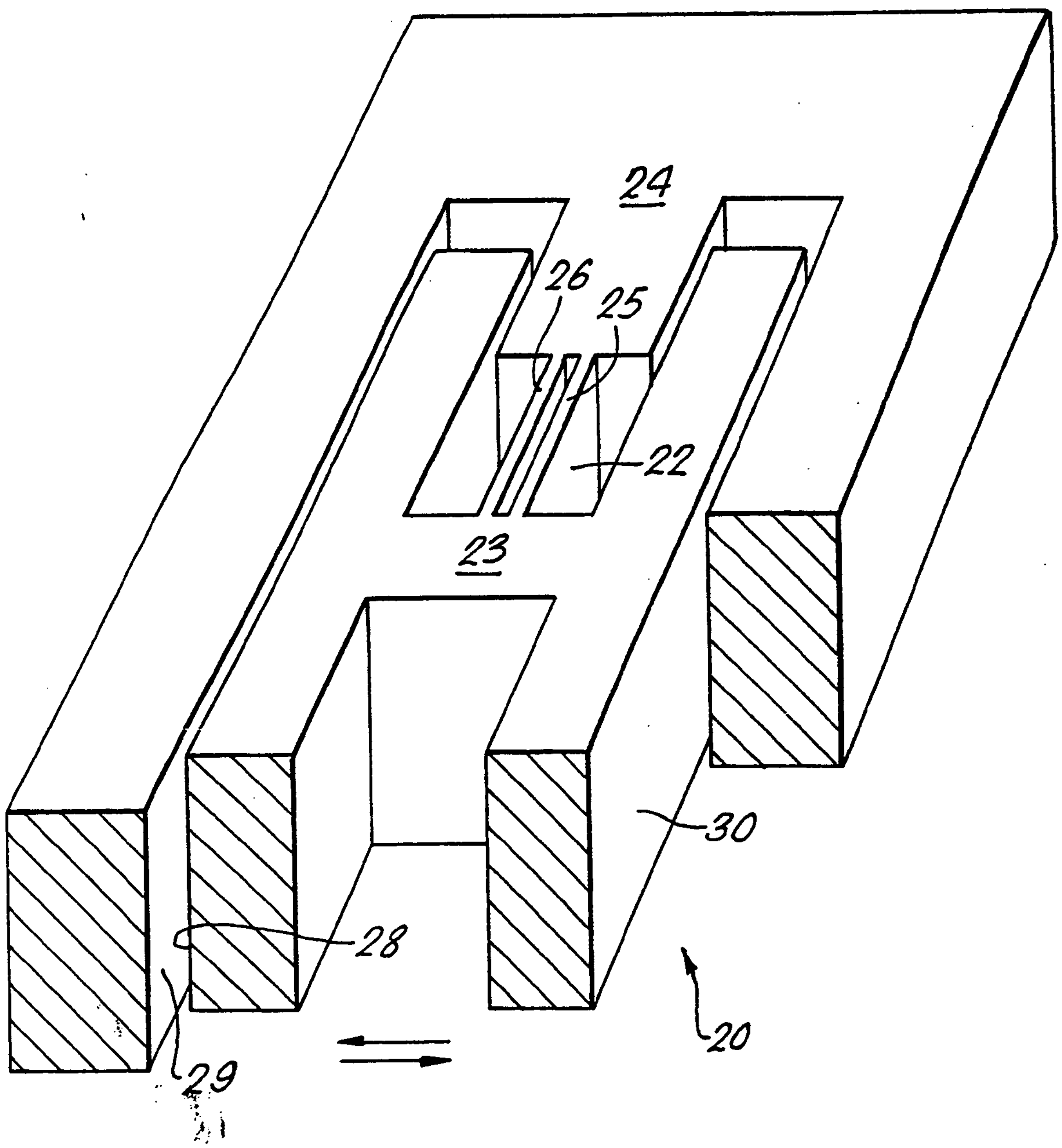


Fig. 3.

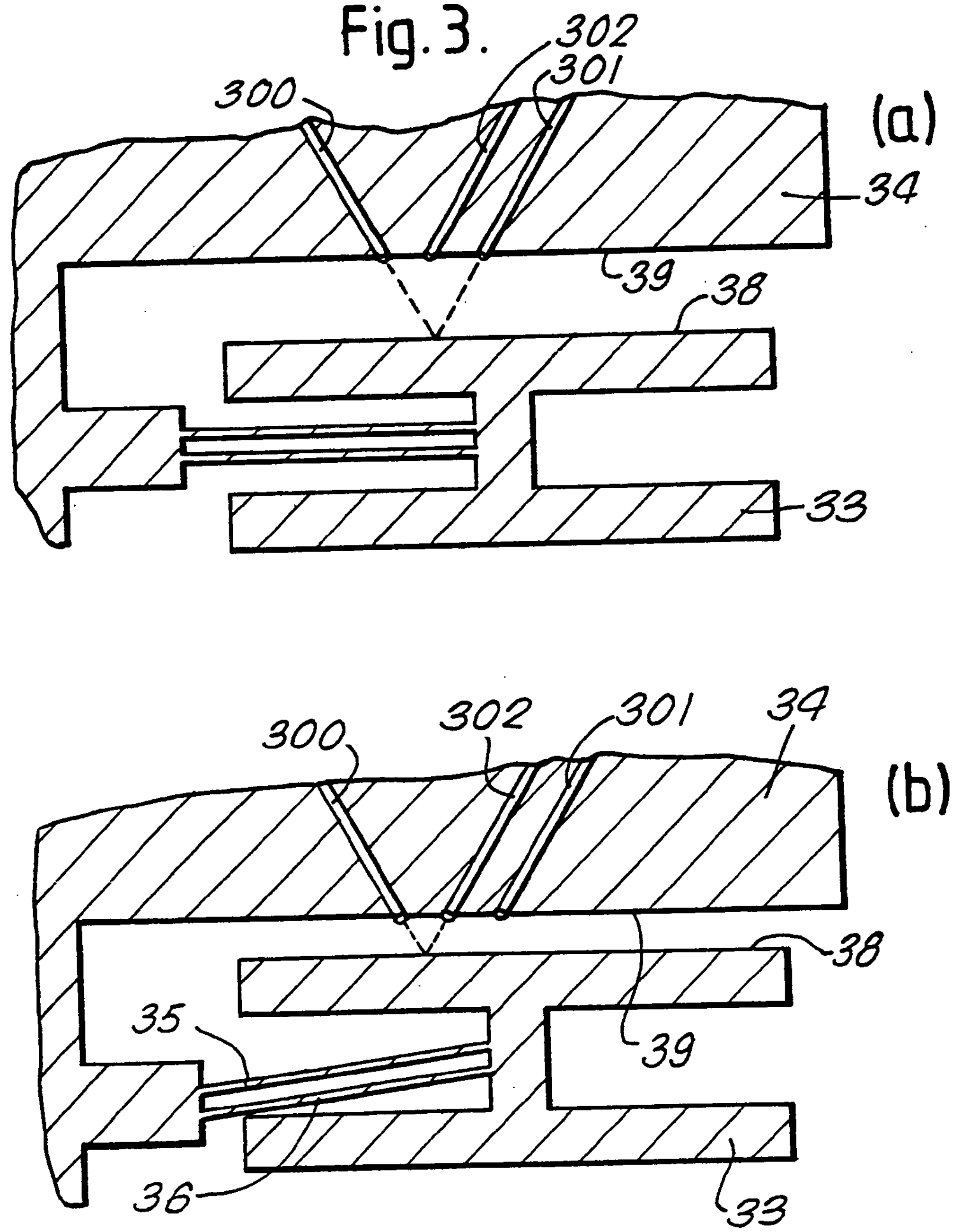


Fig.4.

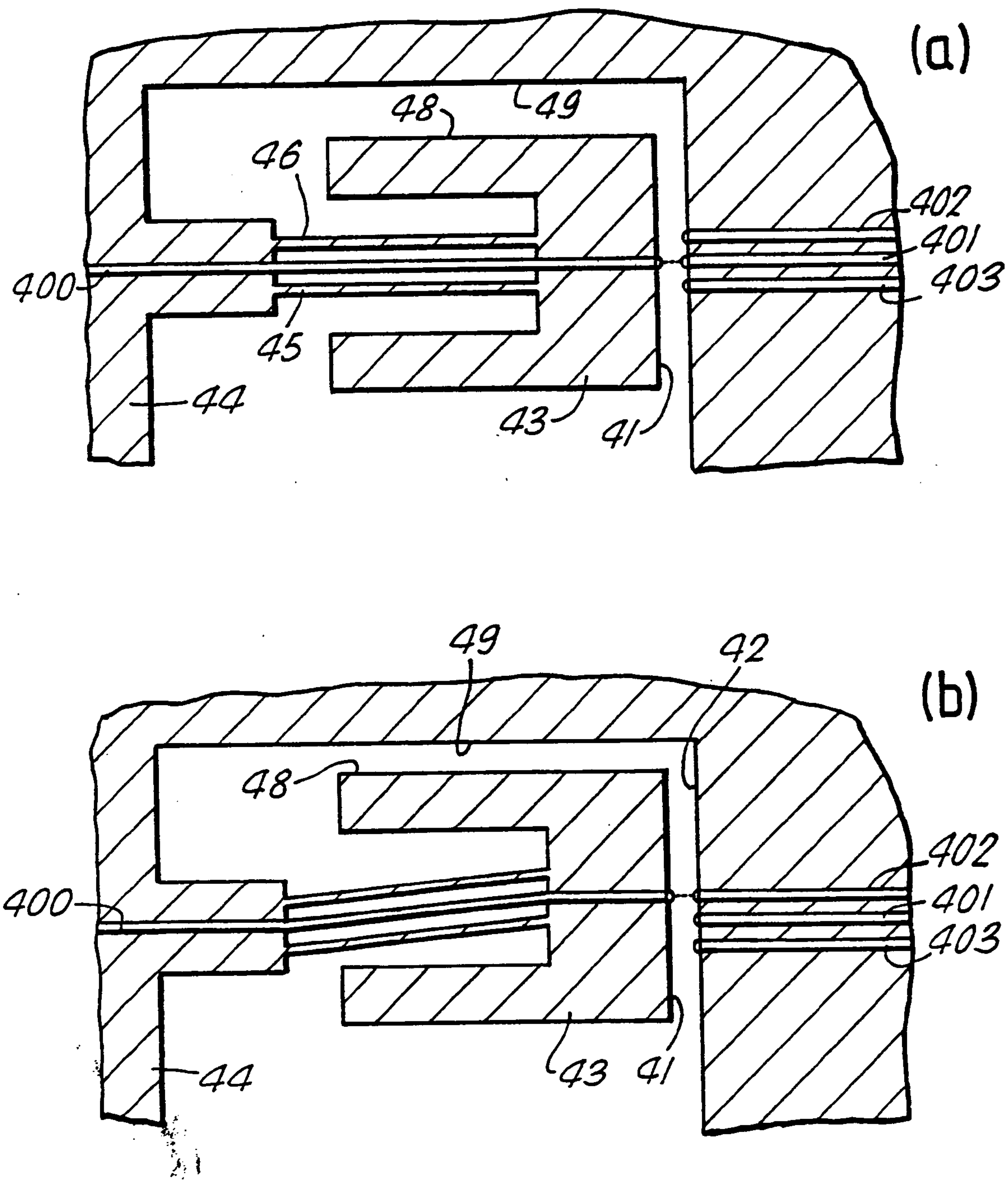

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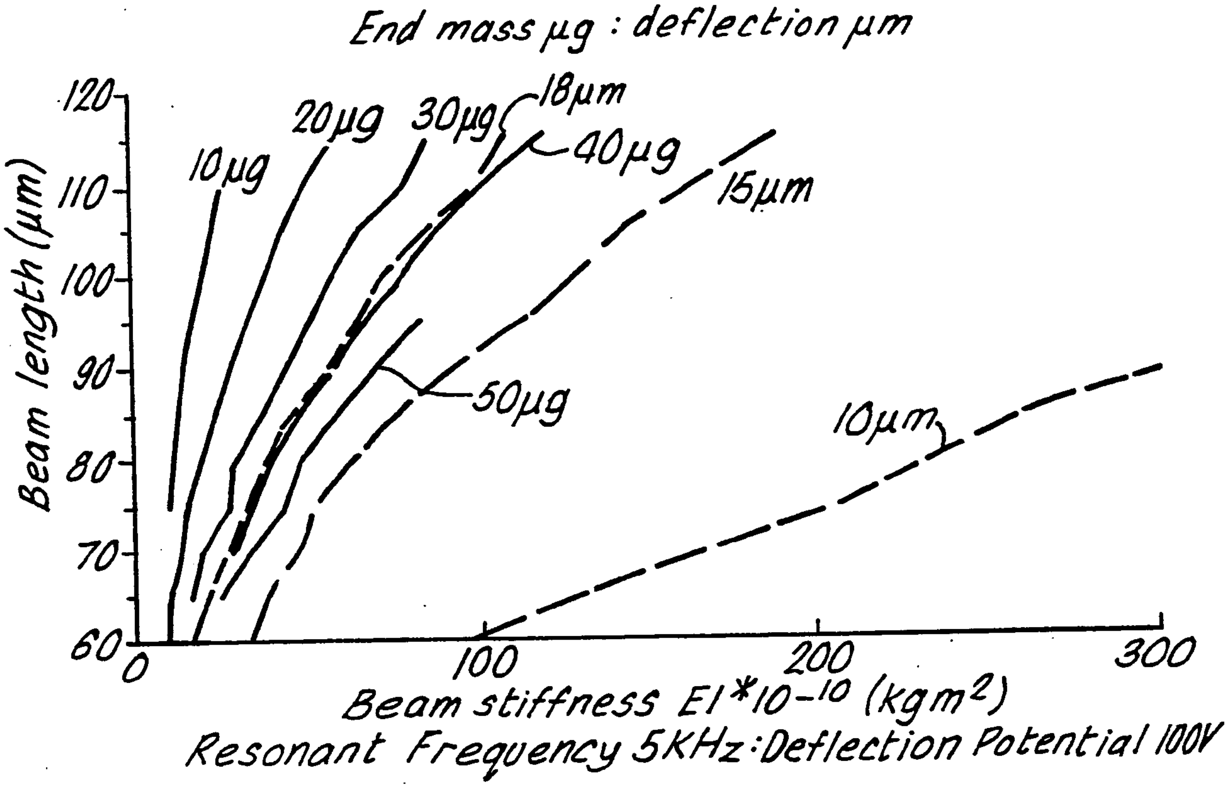
Fig.5.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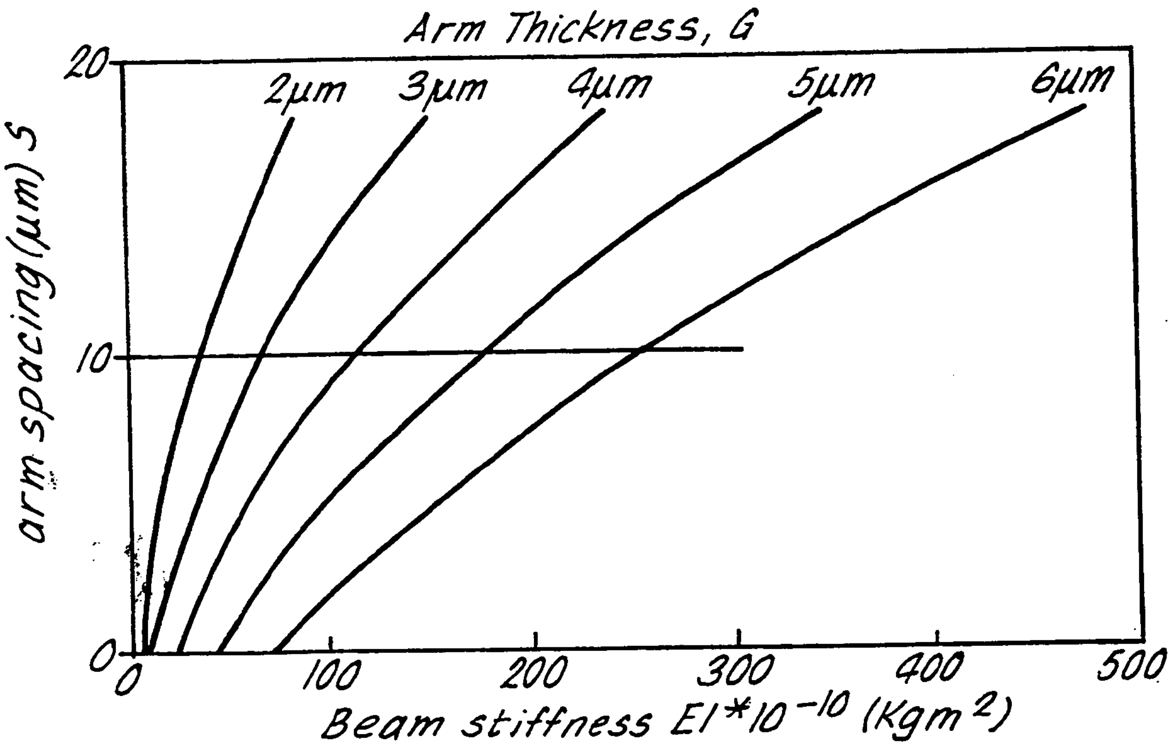
Beam stiffness EI*10⁻¹⁰ (kgm²)
Resonant Frequency 5KHz: Deflection Potential 100V

Fig.6.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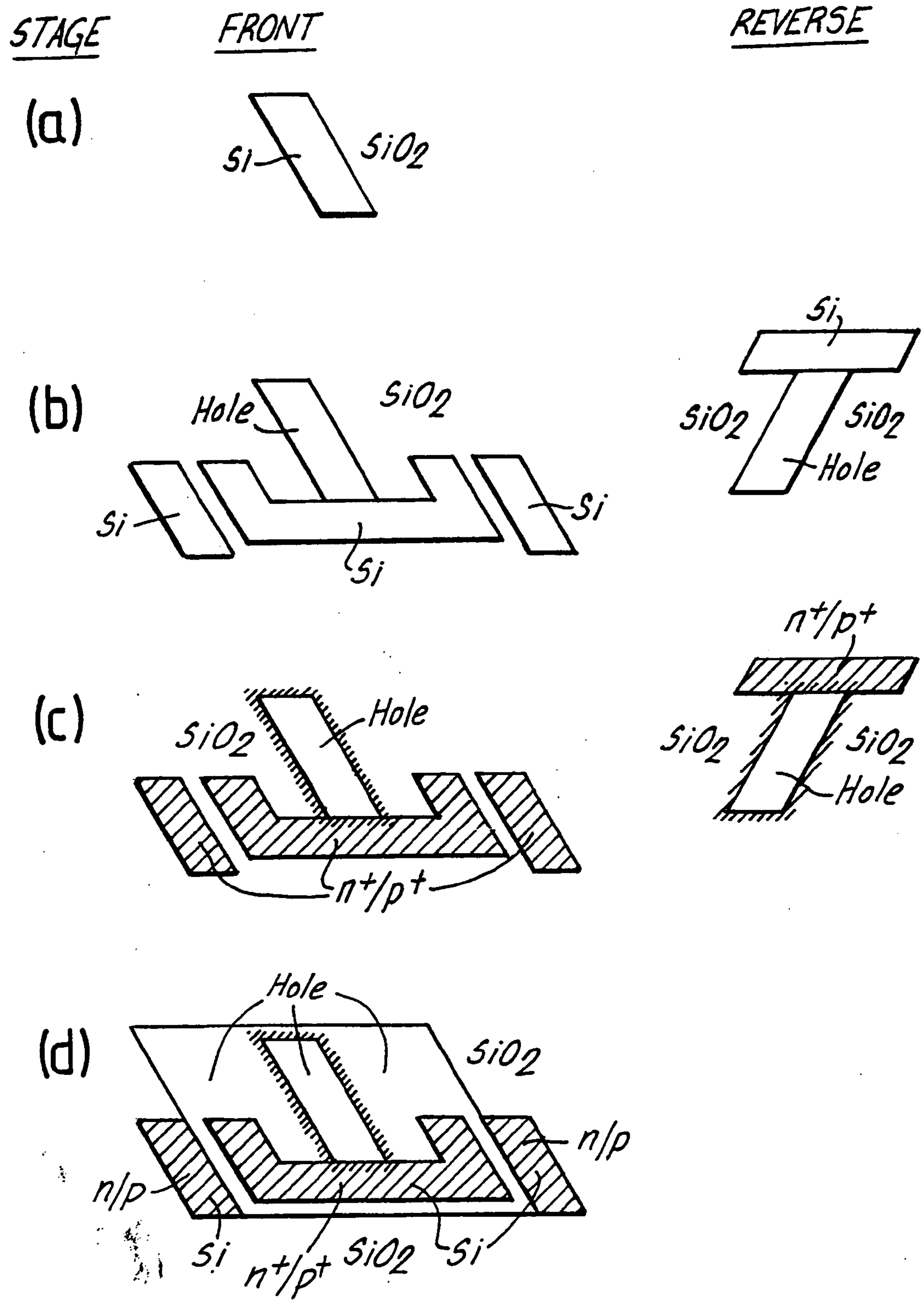
Beam stiffness EI*10⁻¹⁰ (Kgm²)

Fig.7.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Si
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SiO2
Si

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 88 30 2979

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	US-A-4 303 302 (H. RAMSEY) * Figures 1-3; column 3, lines 3-40 * ---	1-4,8,9	G 02 B 26/02
A	US-A-4 626 066 (F. LEVINSON) * Figures 5,6; column 3, lines 11-68; column 4, lines 1-6 * ---	1,2,6,7	
A	EP-A-0 040 302 (IBM CORP.) * Figures 7,8; claims * ---	1	
A	EP-A-0 001 000 (WESTERN ELECTRIC CO.) * Figures; claims; page 2, lines 9-33 * ---	1	
A	US-A-3 758 199 (J. THAXTER) * Figures 1,2; claims * -----	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			G 02 B 26/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	01-07-1988	WESBY P.B.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

Fig.1.

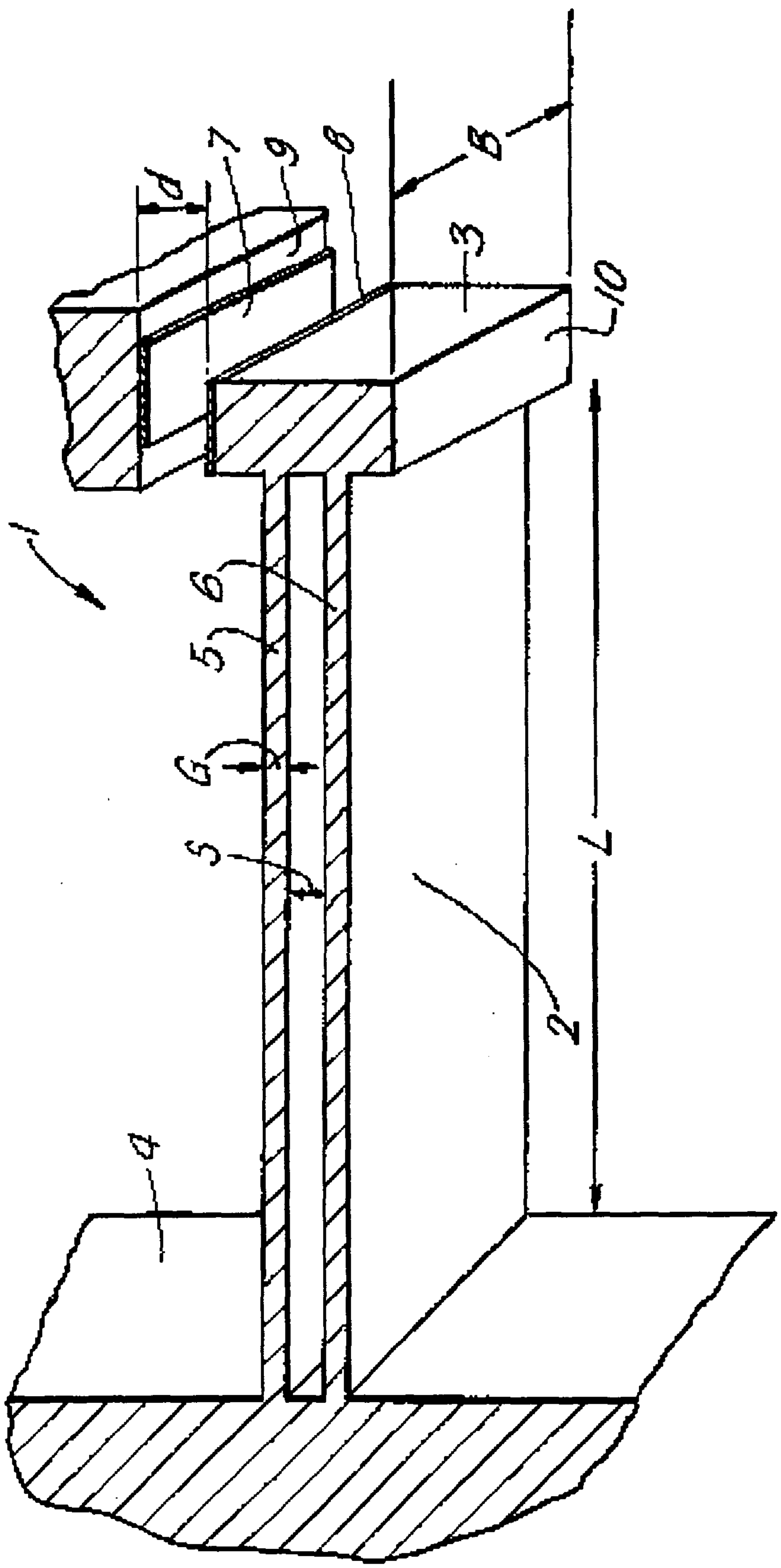


Fig. 2.

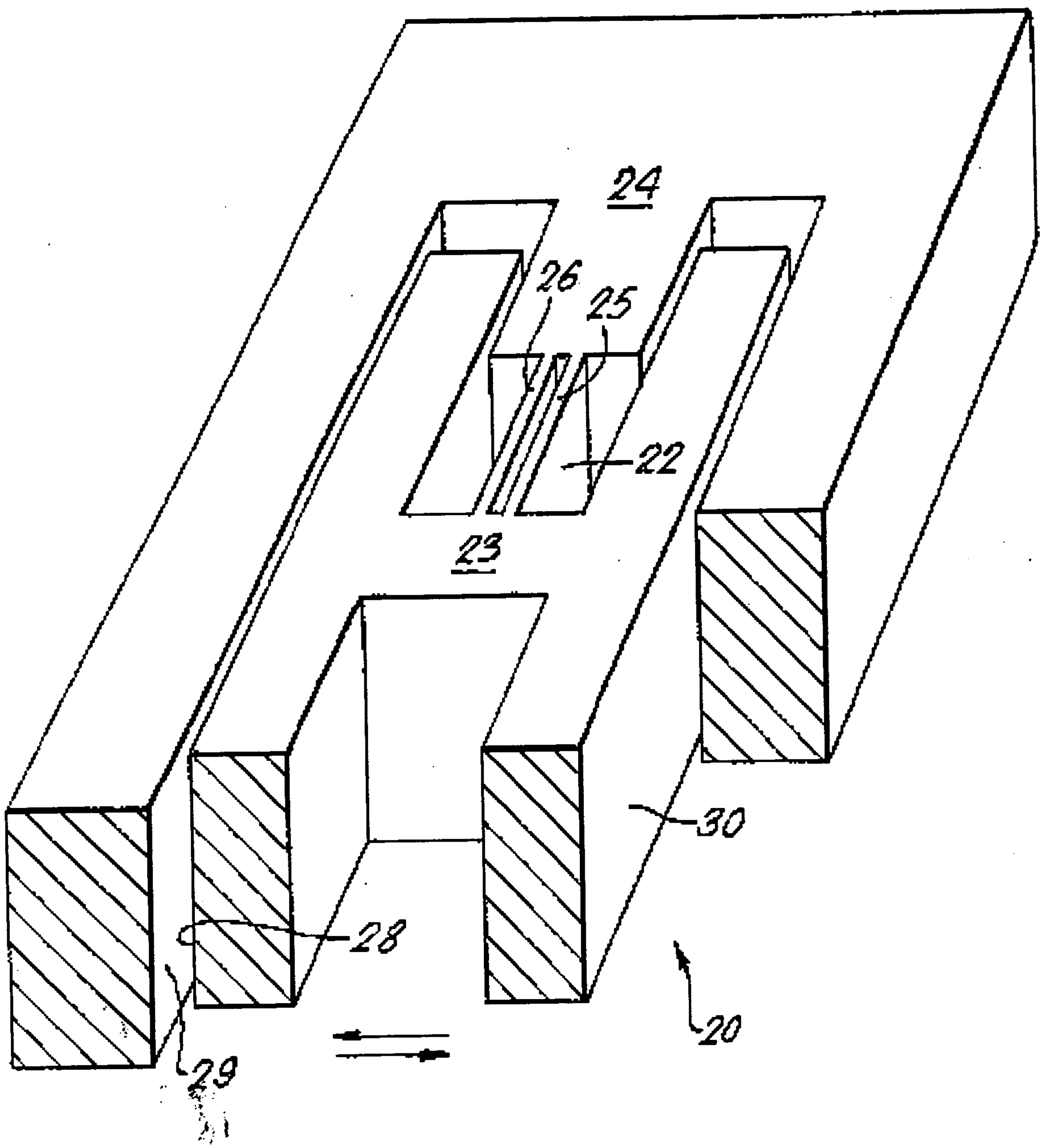


Fig. 3.

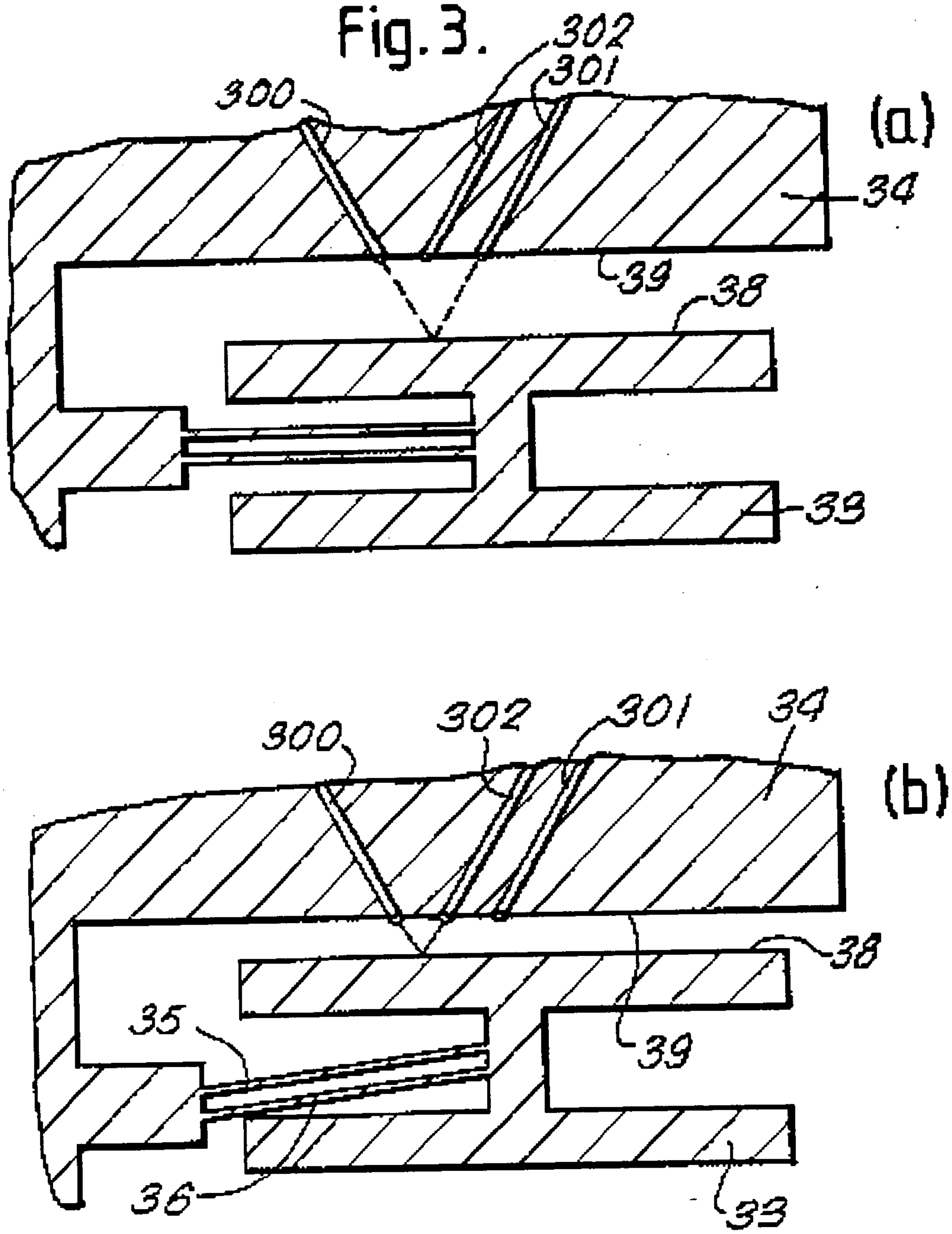
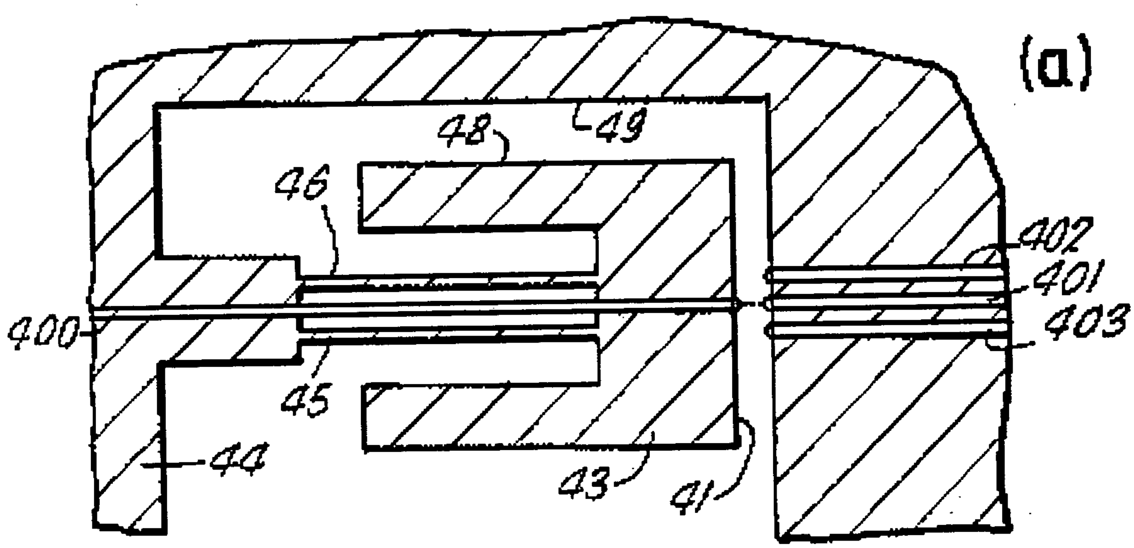


Fig.4.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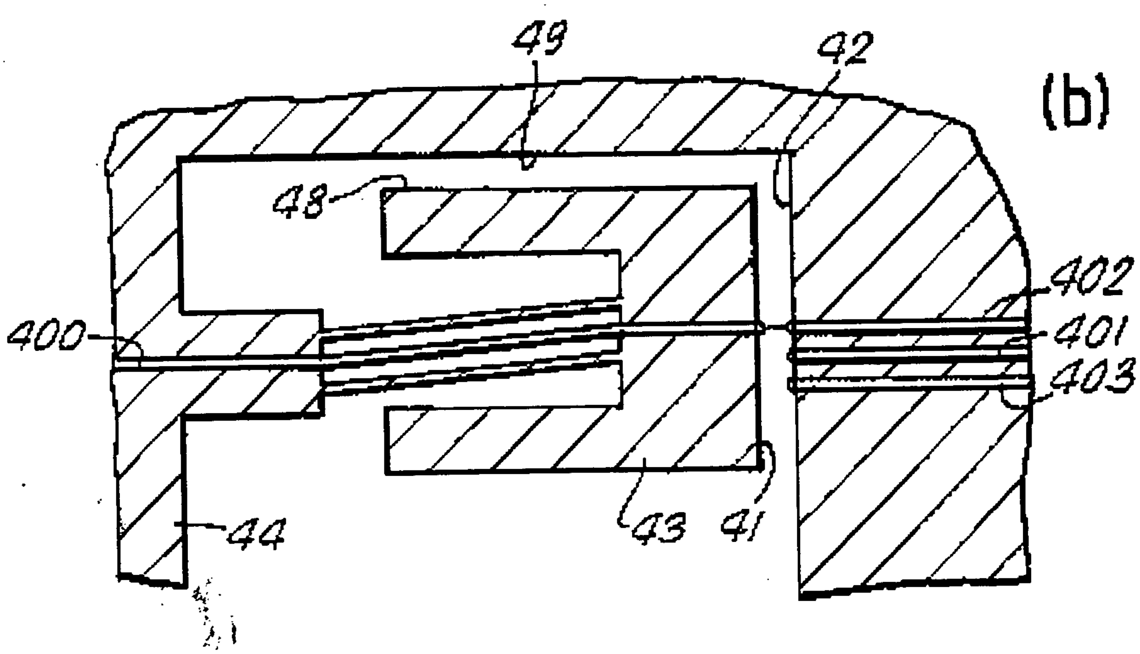
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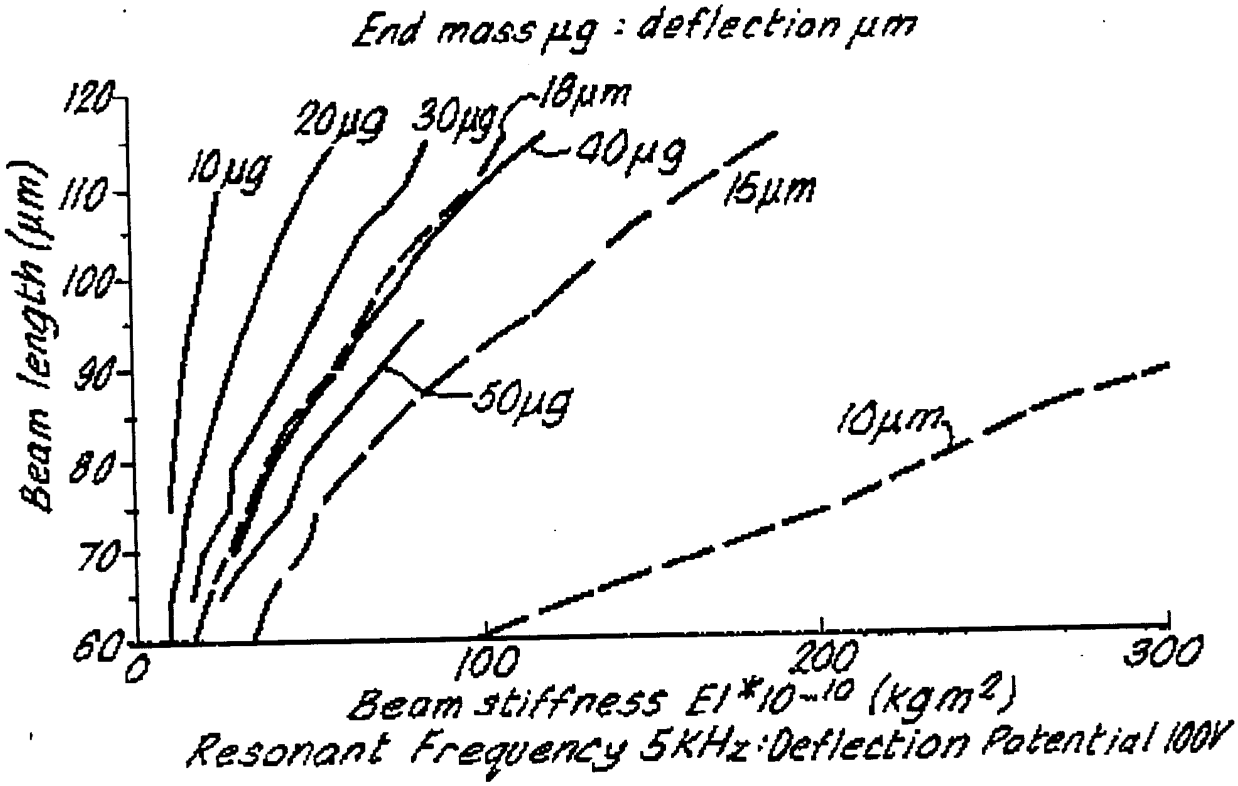
Fig.5.


End mass µg : deflection µm
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10µg
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15µm
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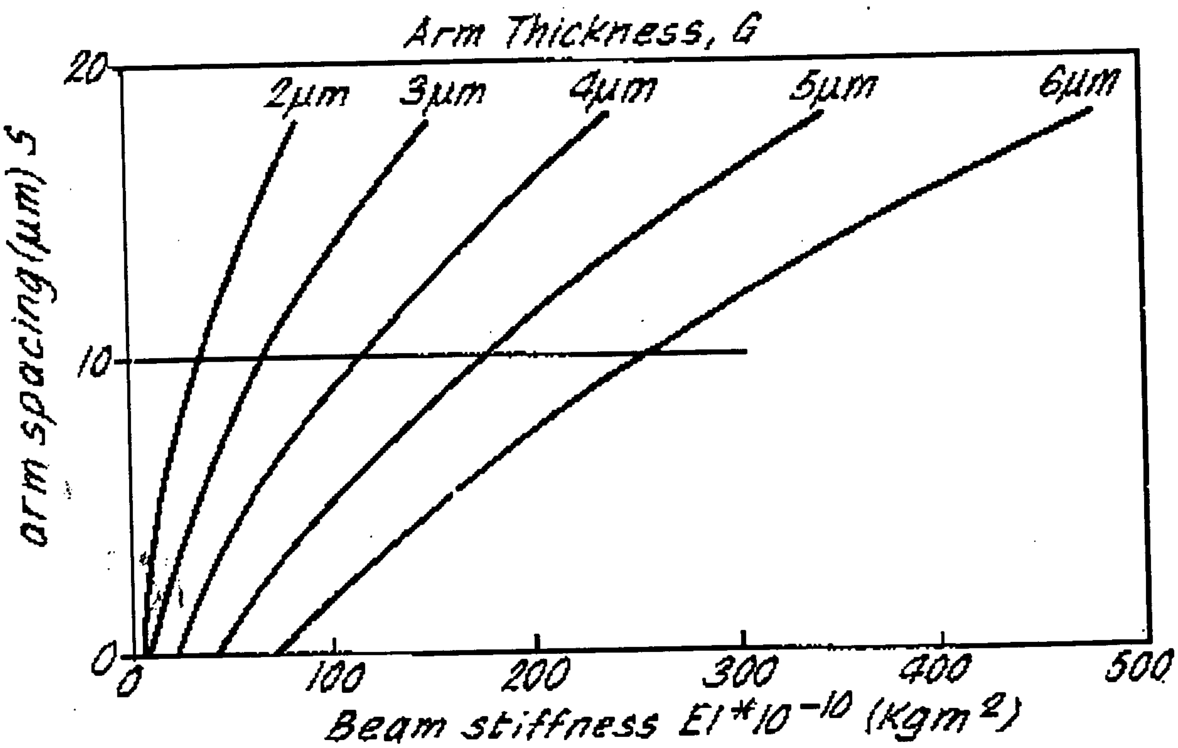
10µm
Beam stiffness EI*10^-10 (kgm^2)
Resonant Frequency 5KHz:Deflection Potential 100V

Fig.6.


Arm Thickness, G
arm spacing (µm) S
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2µm
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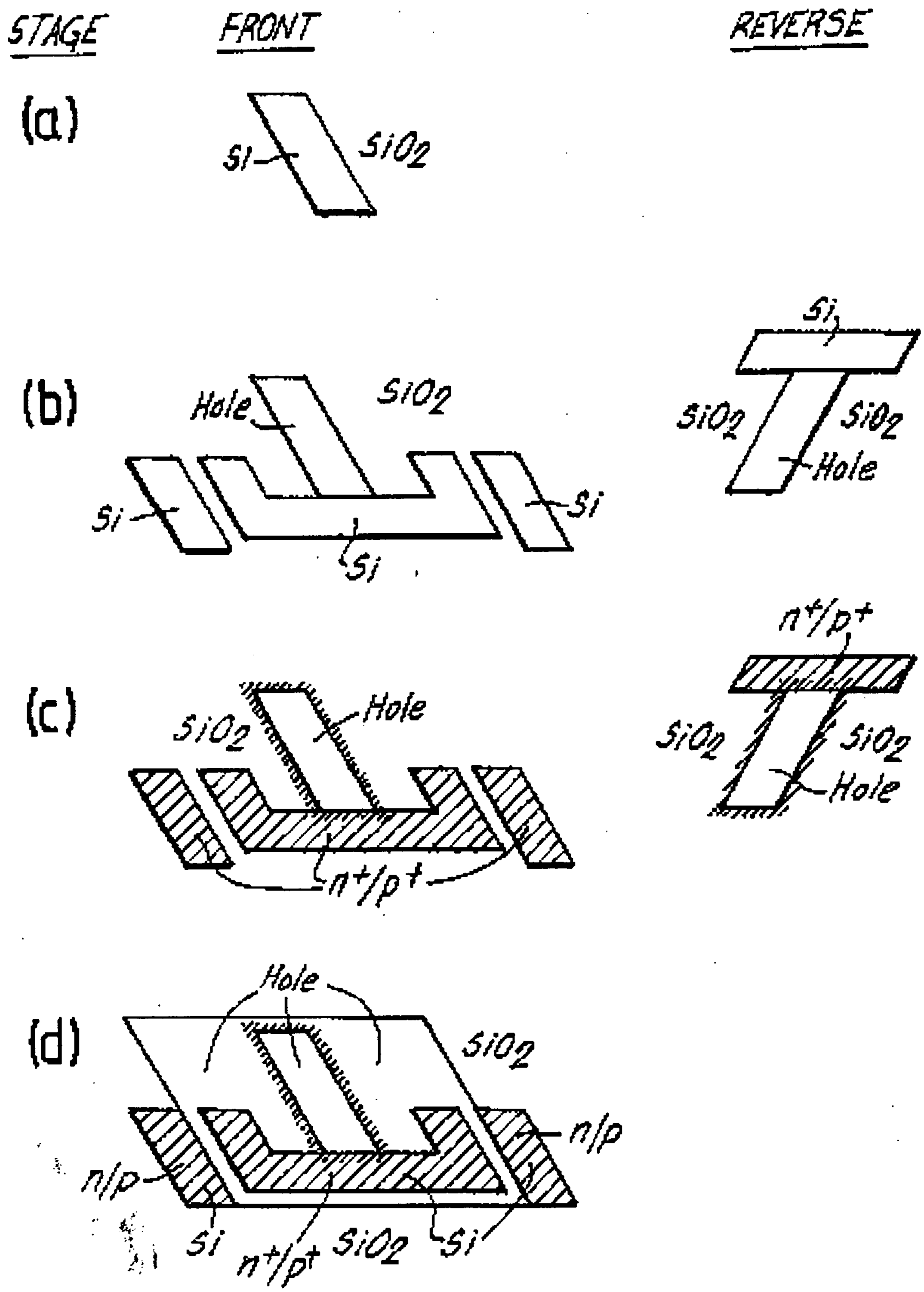
Beam stiffness EI*10^-10 (Kgm^2)

Fig.7.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(19) Europäisches Patentamt
European Patent Office
Offic europé n des brevets

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(12) # EUROPEAN PATENT APPLICATION

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(30) Priority: **26.04.91 US 691920**

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(54) **Deformable mirror shutter device.**

(57) A device comprising a micro-mechanical switch which includes an electrode (38a, 38b) a gap between the electrode and an individually deflectable element (32), which has a vertical shutter (40) attached to its underside. When the electrode is addressed the movement of the deflectable element (32) causes the shutter to raise or lower. Such a device can be used in switching. One embodiment of such a use in waveguides is disclosed along with the method of manufacture.

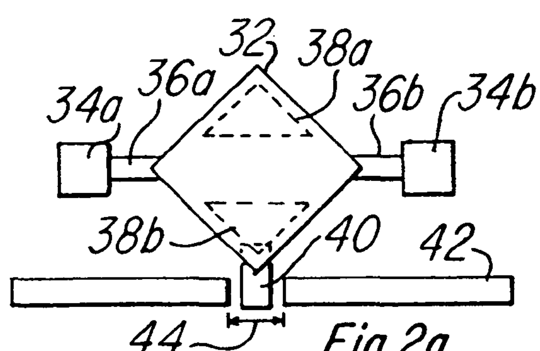


Fig.2a

EP 0 510 629 A1

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention deals with a structure substantially similar to deformable mirror devices (DMDs), and more specifically with a device that has individually deflectable elements.

2. Background of the Invention

Deformable mirror devices (DMDs) normally consist of a reflective surface suspended over an array or series of electrodes. In some instances, the reflective surface is a thin film membrane. The type of DMDs of concern are another kind, the type where the reflective surface is divided up into individually controllable mirrors, each separate from the others.

These DMDs are normally manufactured by forming an array of electrodes on a substrate, covering the array of electrodes with a polymer spacer, covering the spacer with metal, which is patterned to form access holes and to form the individual mirrors and hinges, then etching out the spacer layer, leaving portions of the spacer to support the mirror metal. In some DMD structures, all of the spacer layer is removed and metal posts are used to support the mirrors. The resultant individual mirrors consist of an addressing electrode, at least one support post, and a mirror suspended over an air gap over the electrode.

Some of the configurations of these devices are the cantilever beam, the torsion beam and the flexure beam. The cantilever beam DMD has a mirror supported on one of its sides. The mirror is attached to the support by a single thin hinge allowing freedom of movement. When the electrode underneath the air gap is electrically addressed, the mirror is electrostatically attracted to the electrode and deflects downwards on its hinge. The torsion beam DMD is attached by two hinges that are on opposite sides of the mirror. This type of DMD typically has two address electrodes. When on of the electrodes is addressed, the mirror is electrostatically attracted to that electrode, causing the mirror to tip to the side on which the addressed electrode is located, torquing about a center beam defined by the two hinges. The flexure beam DMD has four hinges, one on each of four sides. When the single electrode, located directly under the flexure beam, is addressed, the mirror deflects in a piston-like motion.

The applications of these devices cover many areas such as printers, display systems, switching networks and many others. The structure of the DMD device has many possible applications as a switch or controller.

SUMMARY OF THE INVENTION

Objects and advantages will be obvious, and will in part appear hereinafter and will be accomplished by the present invention which provides a structure for raising or lowering a metal shutter. The structure consists of a substrate, an electrode, and a metal element, which may be reflective, suspended over the electrode above an air gap. The metal element has a vertical structure attached thereto. When the electrode is addressed, the metal element deflects causing the attached vertical structure to move with the metal element.

The device is manufactured as follows. An electrode is formed on a substrate. The wafer is coated with an organic polymer spacer. The spacer is patterned and covered with metal. The metal is patterned and etched to form hinges and movable metal elements, which include the vertically attached structures. The wafer is then divided and the spacer level removed to allow the metal elements to move over air gaps.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 shows the process flow for the manufacture of the shutter device.

FIGURE 2a shows a top view of a torsion beam shutter device.

FIGURE 2b shows a side view of a torsion beam device with the shutter in the up position.

FIGURE 2c shows a side view of a torsion beam device with the shutter in the down position.

FIGURE 3a shows a side view of an alternate torsion beam shutter device.

FIGURE 3b shows a top view of an alternate torsion beam shutter device.

FIGURE 4a shows a side view of a flexure beam shutter device.

FIGURE 4b shows a top view of a flexure beam shutter device.

FIGURE 5a shows a top view of a cantilever beam shutter device.

FIGURE 5b shows a side view of a cantilever beam shutter device.

FIGURE 6 shows across-sectional view of the shutter device as a wave guide switch.

FIGURE 7a shows an alternate process flow for a metal shutter device.

FIGURE 7b shows an alternate shutter device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The basic DMD structure can be altered for many purposes. Because of its ease of deflection, it is particularly adaptable to act as a controllable shutter device, with a vertical structure attached to

the underside or top of the metal element that moves as the metal element moves. A few modifications must be made to the manufacture process of the DMD in order to form this vertical structure called a shutter.

The process flow is shown in Figure 1. In step 10, the determination must be made if the shutter device is to be used in waveguides, since these require different initial steps in manufacture. If the answer is no, the process moves through path 12 to step 14. In step 14, electrodes are formed on the substrate, which may be silicon or gallium arsenide. The electrodes can be formed in many ways, one of which is to deposit, pattern and etch a metal layer. Other ways include forming the electrode in polysilicon, and diffusing or implanting an electrode. After the electrodes are formed, the process flows to step 16 in which the wafer is coated with a polymer spacer layer. As part of this step, and depending on the device type, the polymer can be patterned such that when metal is deposited upon it, support posts and the shutter will be formed. The next step, 18, is when the metal elements, hinges, and shutters are formed by depositing a metal layer, patterning and etching. The first layer of metal is a thin layer for the hinges. This layer also fills the vias to form the posts, if posts are to be used, and the partial vias for the shutters. The thin metal layer is then covered with silicon dioxide which is patterned to cover the hinges. A thicker metal layer is then laid down and masked with silicon dioxide to form the metal elements. Finally, the entire structure is etched and the thick metal is removed everywhere but where the second mask has been left to define the metal elements.

The thin metal is also removed everywhere but underneath the thick metal where it remains, and where the hinges were masked. The shutter can be oriented many different ways with respect to the metal element beam. Some of these orientations are perpendicular, diagonal, off-center, and on-enter. A few of these many orientations will be discussed later. If this device is using vias, the hinge/beam metal fills them, forming support posts. In step 20 the wafer is divided into individual devices, possible by sawing the wafer. After the wafer is divided, the polymer spacer is removed in step 22. If the structure with metal supports is desired, all of the polymer spacer is removed. If vias were not patterned, a portion of the polymer spacer is left to support the metal elements. This allows the metal elements to move freely over the air gap that separates them from their electrodes. Finally, in step 23 the devices are packaged.

The alternate path that can be taken is path 24. This is if the shutter devices are to be used in waveguides. The process then moves from step 10 through path 24 to step 26. In step 26 a lower layer for the waveguide is formed on the substrate. In step 28, the waveguide core is formed, followed by step 30 when the upper layer is formed. The upper waveguide layers are patterned and a gap is etched through the waveguide core. The process then continues to step 14 and flows as described above. The only difference is between the two resultant structures: the first structure has a DMD with a shutter hanging from it over an electrode on a substrate; the second structure has a DMD with a shutter hanging from it over an electrode such that the shutter will enter the waveguide gap when the electrode is addressed.

Figure 2a shows a top view of a torsion beam shutter device. Metal element 32 is suspended over address electrodes 38a and 38b by hinges 36a and 36b. The hinges 36a and 36b are in turn supported by posts 34a and 34b, respectively. The metal shutter 40 is shown in this instance hanging over a gap 44 in a waveguide 42. The side view of this device is shown in Figure 2b. The metal element 32 is unaddressed in this state, with the shutter 40 hanging over the waveguide gap 44. When the addressing electrode 38b, which is hidden in Figure 2b by the waveguide 42, is addressed the metal element deflects towards the electrode, lowering shutter 40 into the waveguide gap 44, shown in Figure 2c. This interrupts any light transmission through the waveguide gap and the device acts as an ON/OFF switch. Alternately, the DMD shutter could be fabricated such that the shutter is within the waveguide gap, or OFF, in the unaddressed state. In this case when the electrode on the opposite side of the metal element from the shutter, 38a, is addressed and the metal element tips the other way, it would lift the shutter out of the waveguide gap, thus allowing light transmission to occur across the gap, or ON, in the addressed state.

Additionally, the device could be operated in an analog fashion. The distance of shutter deflection can be controlle dby the amount of voltage applied to the address electrode. In this manner, the shutter could be partially lowered, to limit the amount of transmitted light in an analog fashion, to any level from full transmission to total cut-off. The is method is in difference to the previous addressing method where transmission attenuation was digital, i.e. only full-on or cut-off.

An alternate embodiment of the torsion beam shutter device is shown in Figure 3a. In this configuration, the axis of the hinges 36a and 36b runs perpendicular to the axis of the waveguide 42. The shutter 44 also runs perpendicular to the axis of the waveguide 42, but still hangs over the gap 44. The top view in Figure 3b shows the location of the addressing electrode 38b. Similar to the above

discussed configuration, when the electrode 38b is addressed, the shutter tips from the unaddressed ON state, into the waveguide 42 and fills the gap 44, blocking light transmission, the OFF state.

Figure 4a shows a flexure beam shutter device. The metal element 32 is suspended diagonally over the gap and supported by four hinges. The top view 4b shows that the shutter 40 is in the center of the metal element 32. The shutter 40 hangs perpendicular to the gap 44 in the waveguide 42. Note that there is only one addressing electrode 38, which resides under a majority of the metal element area. When the electrode 38 is addressed, the metal element moves down on its hinges 46a, 46b, 46c, and 46d. This causes the shutter 40 to enter the gap 44 as in the previous devices.

Another embodiment is the cantilever beam shutter device, shown in Figure 5a. The hinge 36 supports only on one side of the metal element 32. The electrode is similar to that of the flexure beam, in that it resides under a majority of the metal element area. Figure 5b shows the side view of the device. Again, the cantilever beam shutter devices perform as the other devices previously described.

A cross-section taken through the middle of the torsion beam shutter/waveguide device from Figures 2a, 2b and 2c, is shown in Figure 6. Layer 48 is the lower layer formed on the substrate. The waveguide core 50 is on top of the lower layer. Upper layer 52 rests on the core. Address electrodes 38a and 38b are shown in this embodiment on the layer 52. Alternately, the electrodes could be placed elsewhere, as long as they are adjacent the metal elements and can cause them to deflect. Shutter 40 hangs down from metal element 42 into gap 44. The distance across the gap 54 can be patterned to any size desired. In one specific embodiment, the gap is 1 µm wide. The core layer 52 consists of a .25 µm thick layer of Si_3N_4, sandwiched between to 2.5 µm thick layers of SiO_2. Another possible structure could have the shutter oriented on top of the element instead of hanging underneath it. This embodiment could be adapted to any of the above discussed devices. This alternative structure is shown in the torsion beam embodiment in Figure 7a. The movable metal element has the shutter structure 40 on the top of it. In this embodiment, the axis of waveguide 42 is to the side of the metal element structure. When electrode 38a is electrically addressed, the metal element deflects towards it, lowering the shutter 40 into the gap 44. As discusses above, this device could also be operated in an analog fashion, wherein the distance of deflection, hence, the amount of light passing through is controlled by the amount of voltage applied.

A process flow for the shutter device with the shutter mounted on the top surface of the device is shown in Figure 7b. The flow is the substantially the same as in Figure 1, except in three of the main flow steps. In Figure 7b,the first difference occurs in step 56, where the spacer is coated on to the wafer. The spacer could be patterned with vias for posts if desired, as in Figure 1. The partial vias for the shutter can be eliminated. The shutter does not hang from below the metal element in this embodiment.

The next difference is in step 58, at which time the hinges and elements are formed. In Figure 1, the hinges, elements and shutters could have been formed by laying down a thin metal layer, masking it, laying down a thick metal layer, masking it, and etching all of the metal. This process is similar except that the first layer will not be filling a partial via for the shutter as in Figure 1. Additionally, the final etch of the metal layers is not accomplished in this step. Step 60 could be added to the process from Figure 1. This step is necessary because the shutter has not been formed yet. The metal layers formed in step 58 consist of thin metal, a mask, thick metal and another mask. No etching has been done yet. In step 60, another layer of metal could be deposited and masked to form the shutters. Then all three layers of metal and masks could be etched, leaving three layers at the shutter, two layers at the metal element, and one layer at the hinge. The thickness of each layer can be varied to arrive at the optimal structure.

The applications of this structure as a switch go beyond that in waveguides. It would be possible to use this type of device in many other applications as well. The switching speed and compactness of this structure make it superior over many micromechanical switches currently available.

Thus, although there has been described to this point a particular embodiment for a DMD shutter device, it is not intended that such specific references be considered as limitations upon the scope of this invention except in-so-far as set forth in the following claims.

In particular and in accordance with one aspect of the present invention a deflectable device comprises:

a) a substrate;

b) an electrode formed upon said substrate;

c) at least one support structure formed upon said substrate next to said electrode;

d) a movable metal element attached to said support structure above said electrode, whereby said metal element deflects toward said electrode when said electrode is activated;

e) an air gap between said electrode and said element; and

f) a vertical structure attached to said element, whereby said vertical structure moves with said

deflectable element when said electrode is activated and said vertical structure is attached such that said vertical structure extends further than said metal element.

In accordance with a further aspect of the present invention a deflectable device comprises:

a) a substrate;

b) a lower sheath upon said substrate;

c) a waveguide core upon said lower sheath;

d) an upper sheath upon said waveguide core;

e) a deformable metal element structure comprising a metal element and a vertical structure attached to said metal element, said structure suspended over said waveguide core, separated from said core by an air gap; and

f) an electrode located adjacent said air gap for electrically addressing said metal element, whereby when said electrode is activated said metal element deflects toward said electrode, and said vertical element attached to said metal element is lowered into said gap in said waveguide, thereby preventing transmission of light through said gap.

Claims

1. A deflectable device comprising:
   a) a substrate;
   b) an electrode formed upon said substrate;
   c) at least one support structure formed upon said substrate next to said electrode;
   d) a movable metal element attached to said support structure above said electrode;
   e) an air gap between said electrode and said element; and
   f) a vertical structure attached to said element.

2. The device of Claim 1 wherein said surface is attached to said support structure by at least one hinge.

3. The device of Claim 1 wherein said surface is attached to said support structure by a plurality of two hinges.

4. A method of manufacture comprising:
   a) forming electrodes upon a substrate;
   b) coating said electrodes with a polymer spacer;
   c) patterning said spacer;
   d) forming metal layers upon said spacer;
   e) patterning said metal layers to form hinges, metal elements and structure vertically attached to the underside of said metal elements;
   f) dividing said substrate into individual devices;
   g) removing a portion of said spacer from said devices; and
   h) packaging said individual devices.

5. A method of manufacture comprising:
   a) forming electrodes upon a substrate;
   b) coating said electrodes with a polymer spacer;
   c) forming metal layers upon said spacer;
   d) patterning said metal layers to form hinges, and metal elements;
   e) forming a metal shutter layer upon said metal layers;
   f) patterning said shutter layer;
   g) removing portions of said shutter layer and said metal layers;
   h) dividing said substrate into individual devices;
   i) removing a portion of said spacer from said devices; and
   j) packaging said individual devices.

6. The method of either of Claims 4 or 5 wherein said forming electrodes step comprises depositing, patterning and etching metal.

7. The method of either of Claims 4 or 5 where said forming electrodes step comprises diffusing in a material to act as an electrode.

8. The method of either of Claims 4 or 5 wherein said forming electrodes step comprises forming said electrodes out of polysilicon.

9. The method of either of Claims 4 or 5 wherein said patterning said spacer layer comprises patterning said spacer with partial vias.

10. The method of either of Claims 4 or 5 wherein said removing step comprises removing substantially all of said spacer.

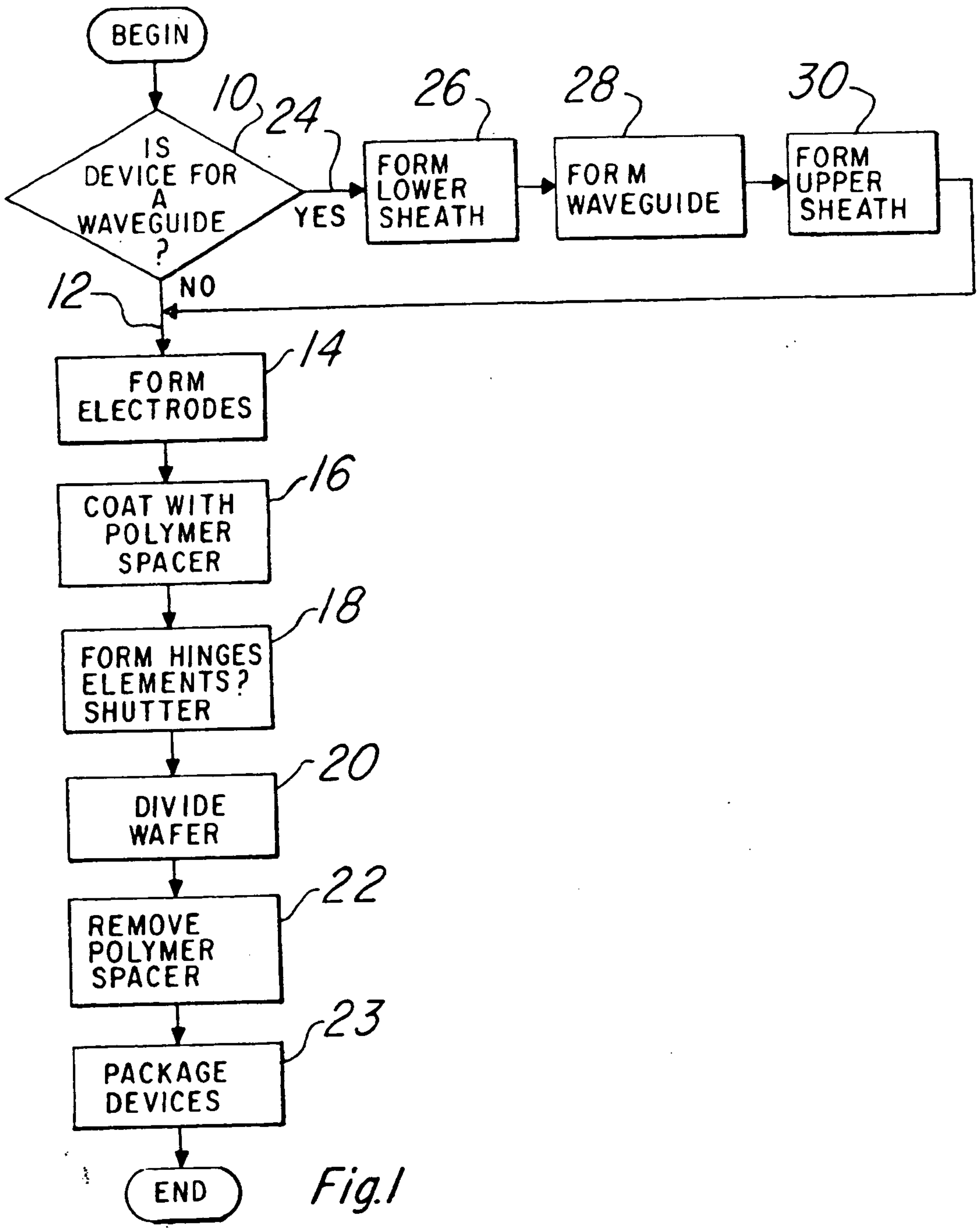
11. The method of either of Claims 4 or 5 wherein said removing step comprises removing a portion of said spacer and leaving a portion of said spacer to act as a support structure.

12. The method of Claim 5 wherein said patterning said metal layers comprises masking said metal layers.

13. The method of Claim 5 wherein said forming said shutter metal layer comprises depositing said shutter layer upon said metal layers.

14. The method of Claim 5 wherein said patterning said shutter layer comprises masking said shutter layer.

15. The method of Claim 5 wherein said removing portions of said shutter layer and metal layers step comprises etching said layers.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IS DEVICE FOR A WAVEGUIDE ?
YES
NO
FORM LOWER SHEATH
FORM WAVEGUIDE
FORM UPPER SHEATH
FORM ELECTRODES
COAT WITH POLYMER SPACER
FORM HINGES ELEMENTS? SHUTTER
DIVIDE WAFER
REMOVE POLYMER SPACER
PACKAGE DEVICES
END
10
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Fig.1

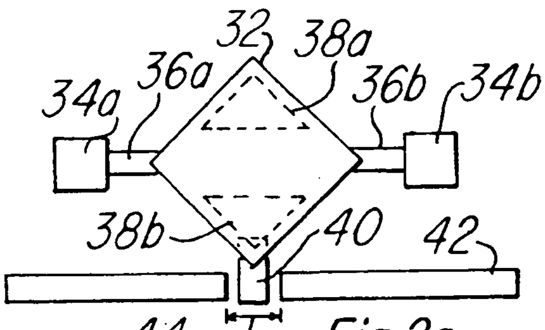


Fig.2a

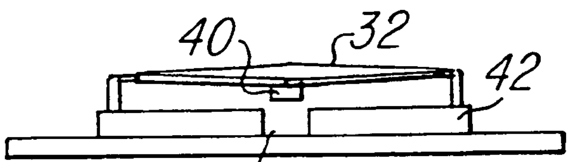


Fig.2b

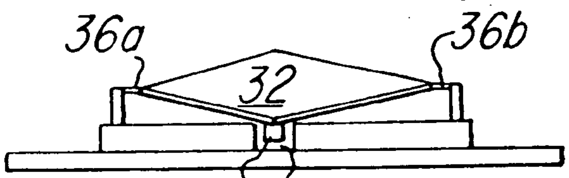


Fig.2c

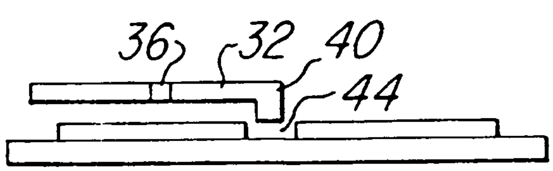


Fig.3a

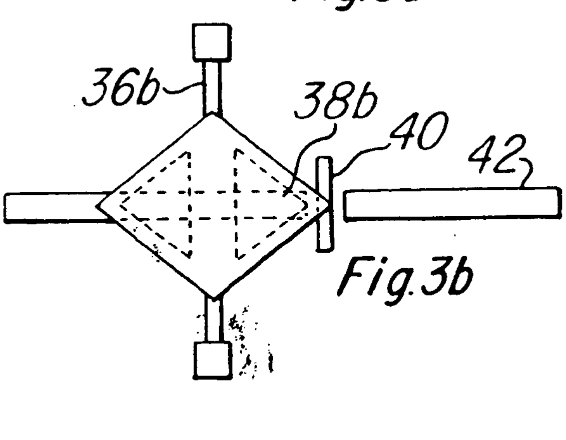


Fig.3b

Fig.4a

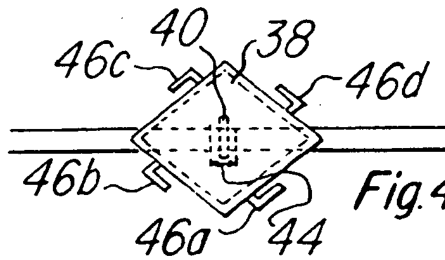


Fig.4b

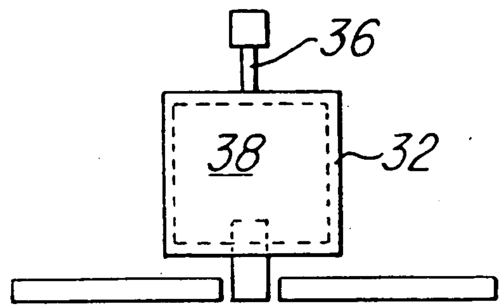


Fig.5a

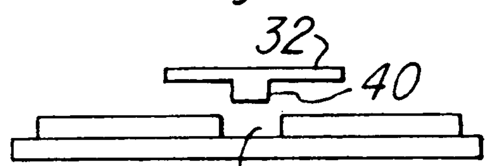


Fig.5b

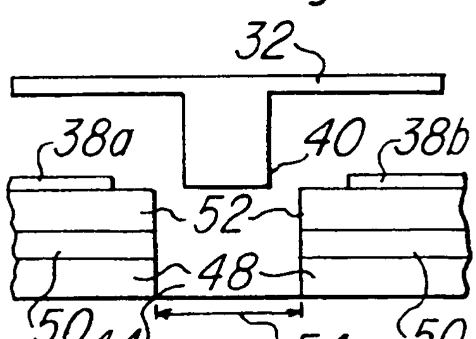
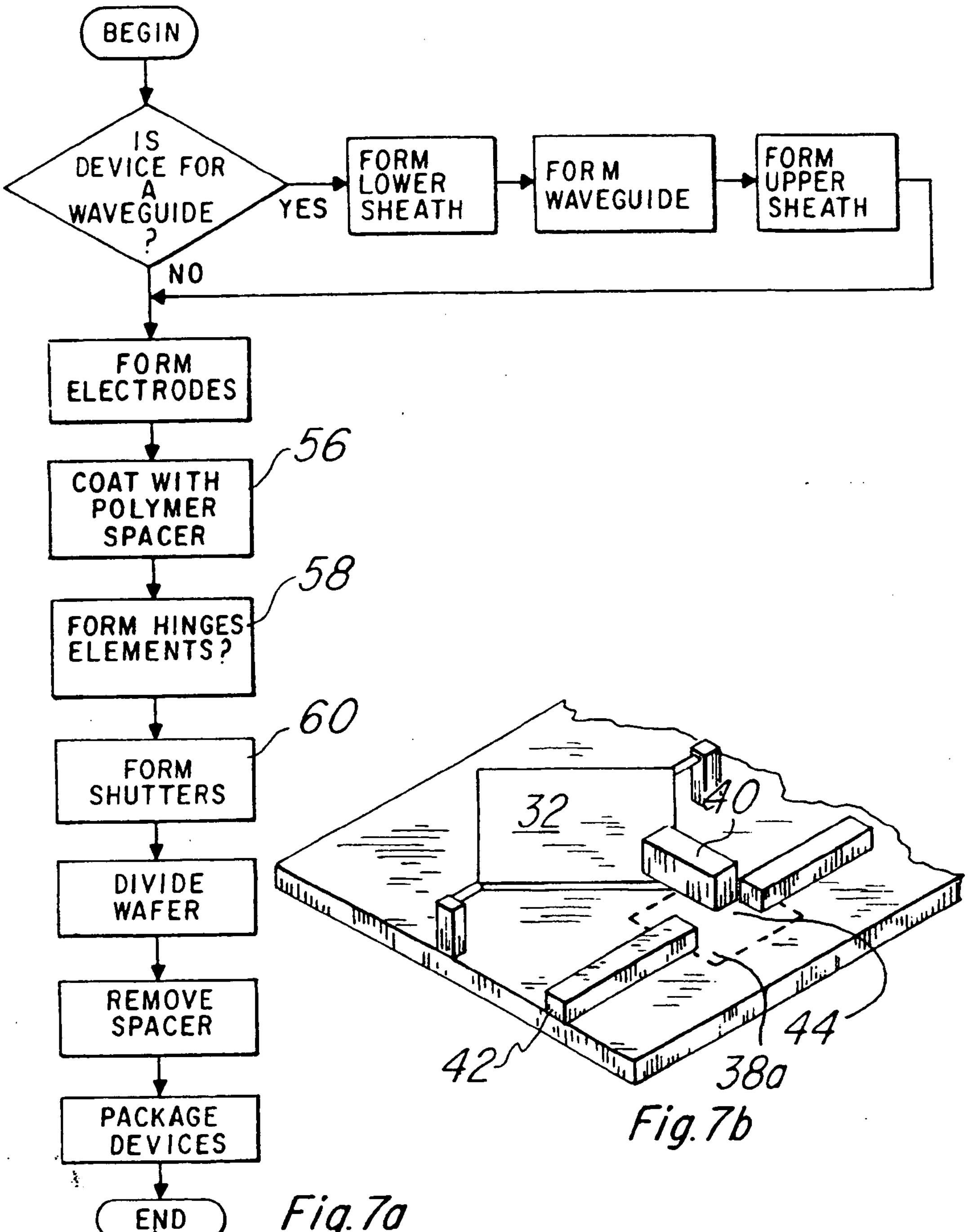


Fig.6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FORM LOWER SHEATH
FORM WAVEGUIDE
FORM UPPER SHEATH
FORM ELECTRODES
COAT WITH POLYMER SPACER
56
FORM HINGES ELEMENTS?
58
FORM SHUTTERS
60
DIVIDE WAFER
REMOVE SPACER
PACKAGE DEVICES
END
32
40
42
38a
44

Fig. 7b

Fig. 7a

European Patent Office

EUROPEAN SEARCH REPORT

Application Number EP 92106928.2

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US - A - 4 580 873 (LEVINSON) * Column 1, line 55 - column 3, line 53 * --	1,2,4, 5	G 02 B 26/02 G 02 B 6/24
A	DE - C - 3 817 035 (MESSERSCHMITT-BÖLKOW-BLOHM GMBH) * Fig. 1-3 * --	1,4,5	
A	WO - A - 89/01 173 (SOULOUMIAC) * Abstract; fig. 1-4 * --	1,2	
A	WO - A - 91/05 284 (BRITISH TELECOMMUNICATIONS) * Fig. 1-7 * ----	4,5	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

G 02 B 6/00
G 02 B 26/00

The present search report has been drawn up for all claims

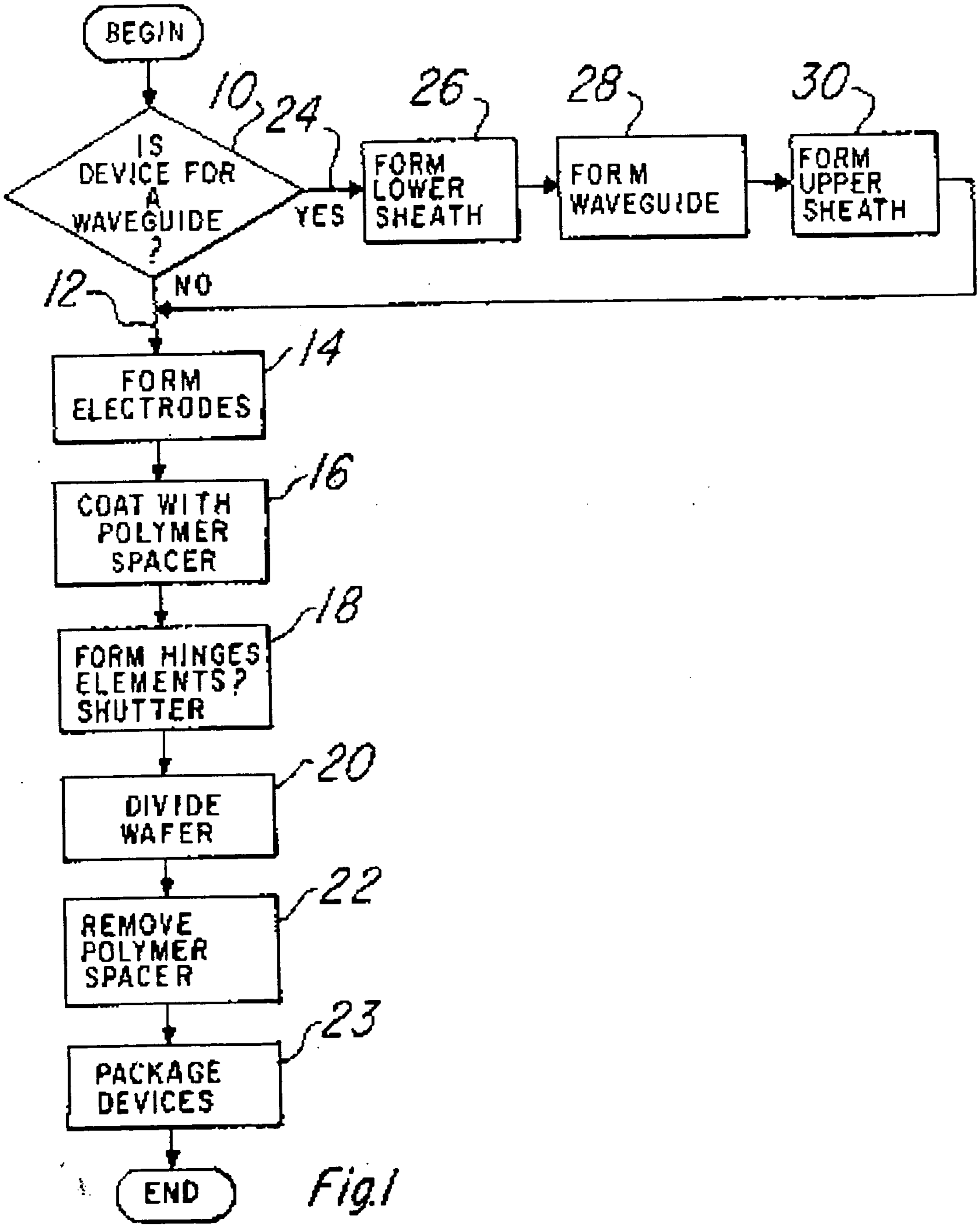
Place of search	Date of completion of the search	Examiner
VIENNA	29-07-1992	GRONAU

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document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12
26
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28
FORM WAVEGUIDE
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COAT WITH POLYMER SPACER
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FORM HINGES ELEMENTS ? SHUTTER
20
DIVIDE WAFER
22
REMOVE POLYMER SPACER
23
PACKAGE DEVICES
END

Fig.1

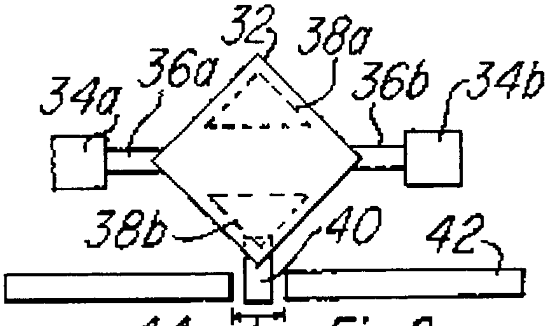

Fig.2a

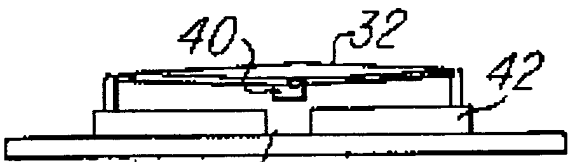

Fig.2b

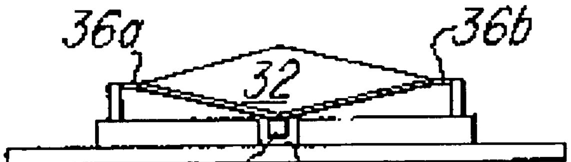

Fig.2c

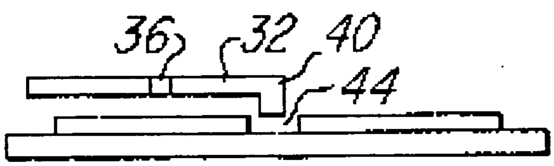

Fig.3a

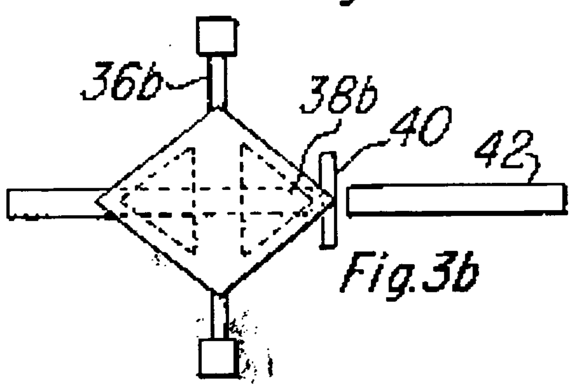

Fig.3b

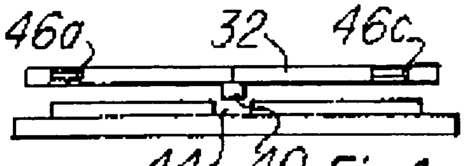

Fig.4a

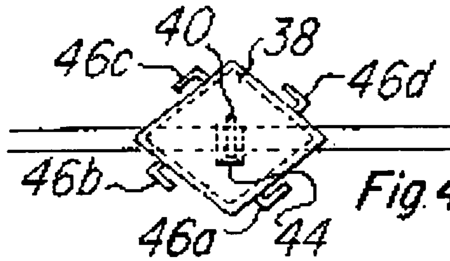

Fig.4b

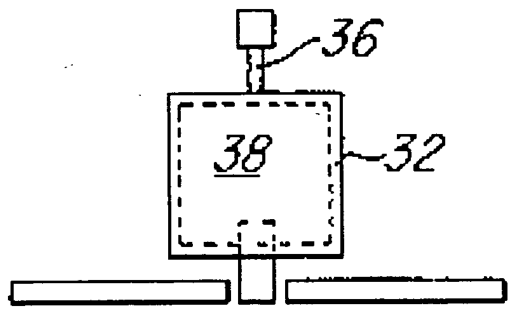

Fig.5a

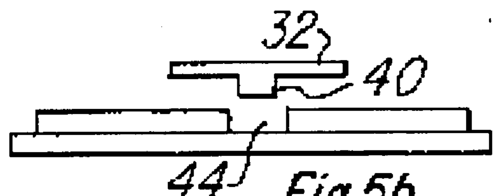

Fig.5b

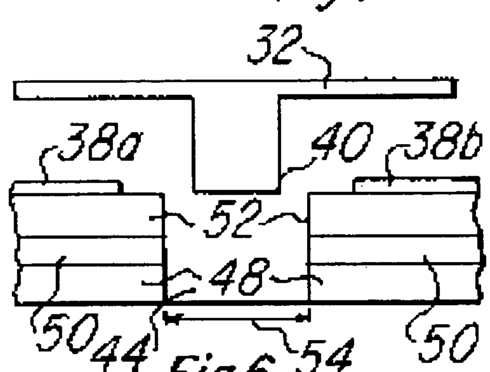

Fig.6

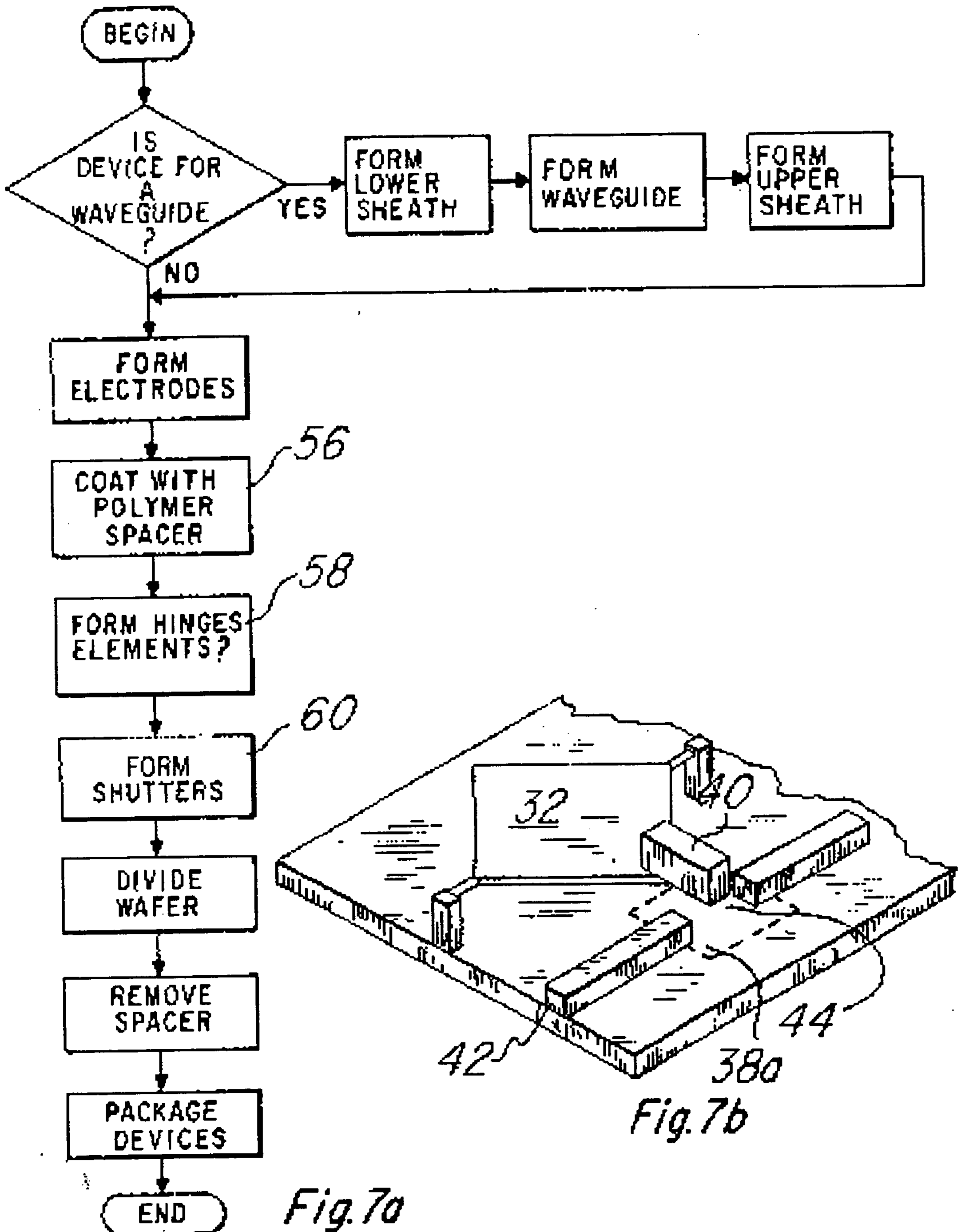
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Fig.7a

32
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Fig.7b